PCSA Tool and Example Application

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Overview

- Background
  - Preclosure Safety Analysis Requirements
  - Preclosure Safety Review Strategy
  - PCSA Tool Capability
- Preclosure Review Methodology
- PCSA Tool Example Problem
- Future Work
- Summary

Preclosure Safety Analysis Requirements

(10 CFR 63.2, 63.21, 63.111, 63.112, and 63.204)

- Preclosure safety analysis is defined as a systematic examination of the site; the design; and the potential hazards, initiating events and their resulting event sequences; and potential dose consequences to workers and the public

- Demonstrate compliance with regulatory performance objectives:

  - Category 1 Event Sequences
    Public Annual Dose Limit: 15 mrem/year, and Worker Dose Limit of 10 CFR Part 20

  - Category 2 Event Sequences
    Public Dose Limit Per Event: 5 rem/event sequence and Organ Dose

- Identify and analyze the performance of the structures, systems, and components (SSCs) that are important to safety

- Establish design bases and design criteria to satisfy regulatory performance objectives

Preclosure Safety Review Strategy

- DOE must demonstrate that the repository will meet regulatory requirements throughout the preclosure period
- Staff will use Yucca Mountain Review Plan (YMRP) to review DOE License Application
- PCSA Tool applies review methods contained in YMRP
- Staff will use PCSA Tool to conduct selected confirmatory analyses
- Staff review will focus on important to safety SSCs
- Staff review will incorporate risk insights from multiple sources

PCSA Tool Capability

- Independent review capability
  - Evaluate completeness of the DOE preclosure safety analysis
  - Evaluate selected portions of the DOE preclosure safety analysis, assumptions, and data

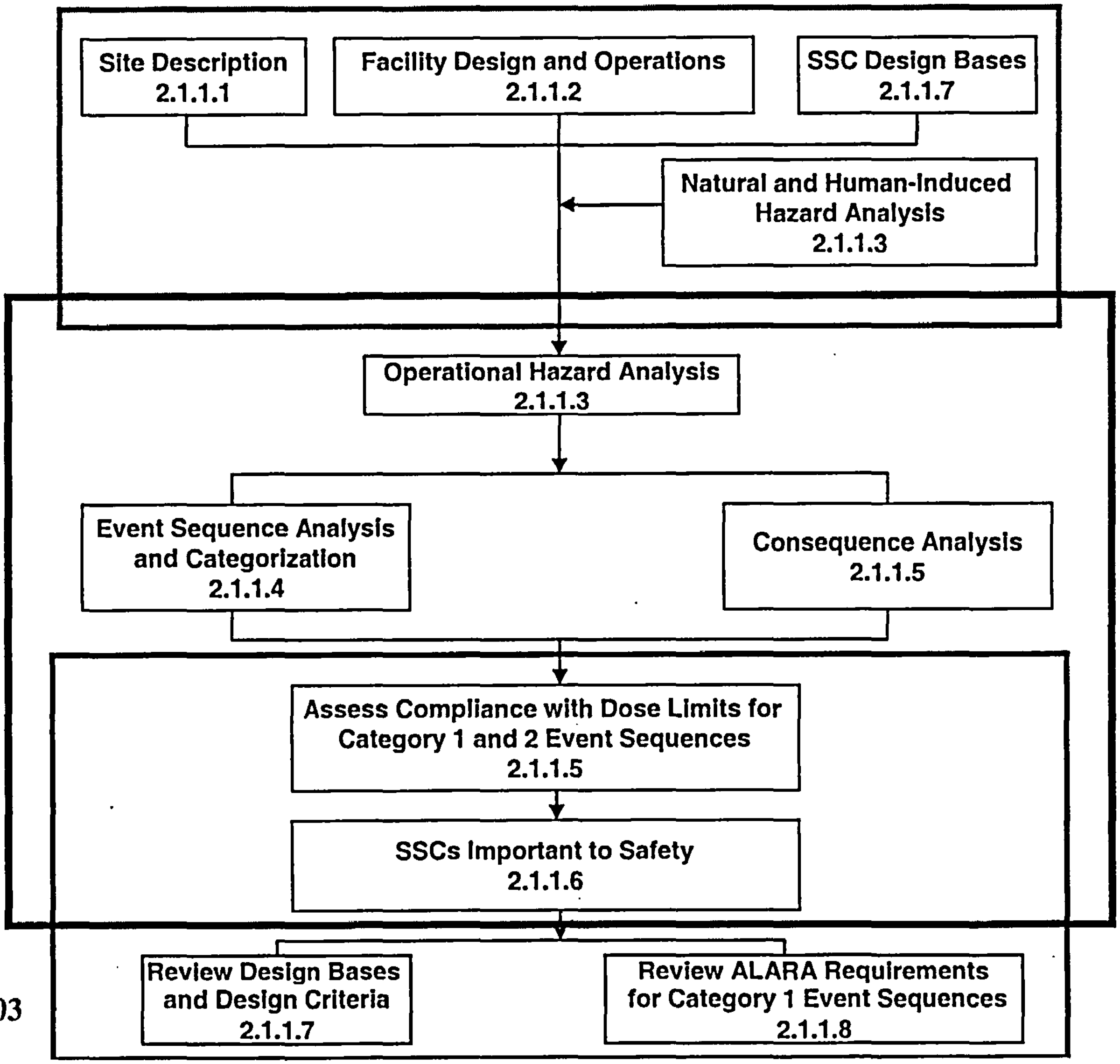
- Enhance staff understanding of DOE preclosure safety analysis
  - Conduct preclosure safety analysis for part or all of the facility
  - Perform independent safety assessment
  - Independently identify SSCs important to safety
  - Develop preclosure risk insights
  - Perform sensitivity and importance analysis
  - Provide framework for systematically documenting staff review

Preclosure Review Methodology

Input to PCSA Tool

PCSA Tool Functions

Objectives of Preclosure Safety Analysis



Analysis of a Conceptual Dry Transfer Facility

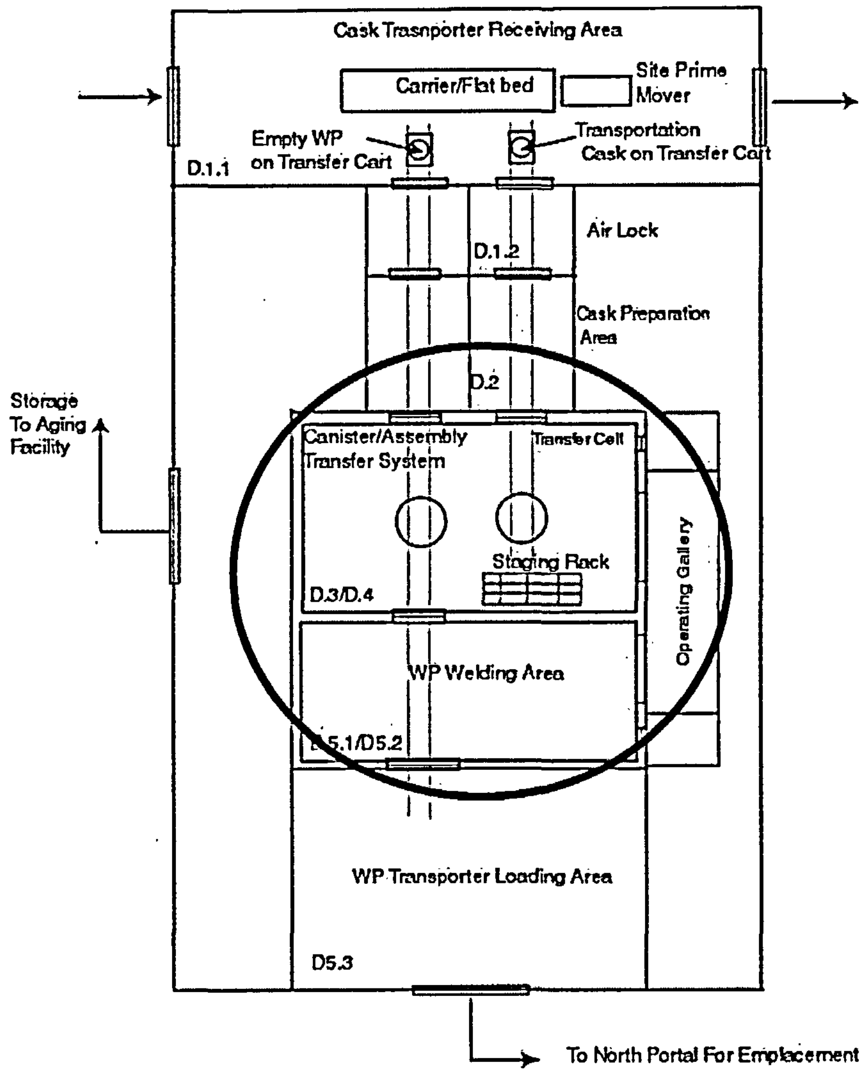
- Staff developed a simplified analysis of a conceptual dry transfer facility, using PCSA Tool and methodology

- Activities performed as part of the analysis consistent with Preclosure Review Methodology

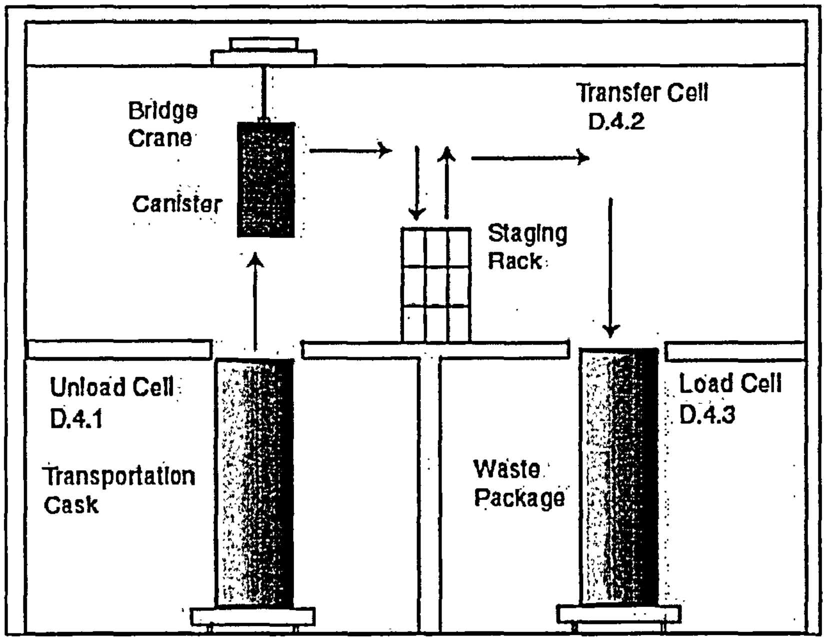
- Staff will conduct similar independent analyses to review DOE preclosure safety analysis

PCSA Tool Example Problem

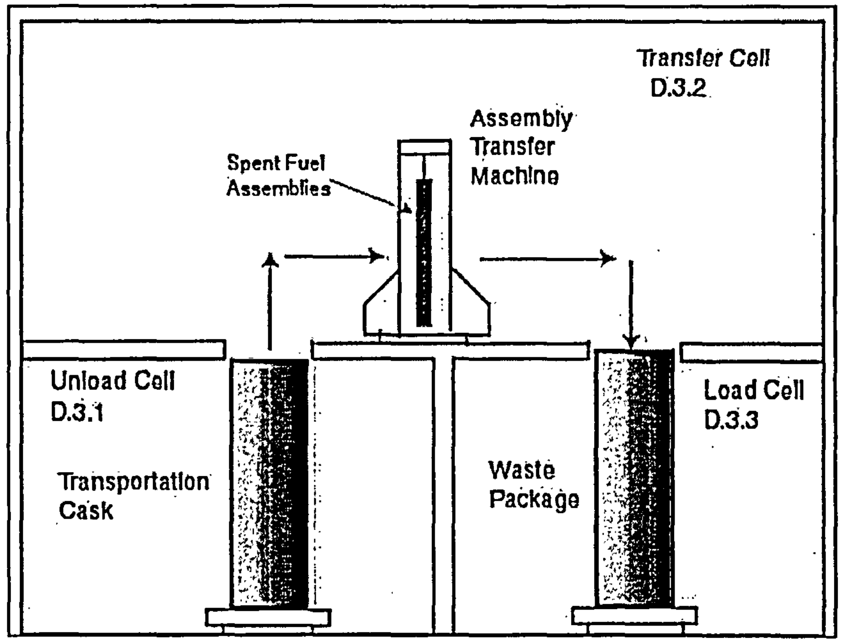
Conceptual Dry Transfer Facility



Conceptual Canister Assembly Transfer System



Canister Transfer



Assembly Transfer

Example Event Scenario

(Canister Drop on Staging Rack in Hot Cell: Material at risk 21 PWR)

Failure of Bridge Crane	Canister Breach	HVAC/HEPA Unavailability	Frequency 1/yr	Category (*)	Consequence	
					Public (**)	Worker
0.026 /yr	No 0.999		2.6×10^{-2}	1	No release	No Dose
	Yes p = 1.0×10^{-3}	No 0.9999	2.6×10^{-5}	2	Probabilistic Mean 3.15×10^{-4} rem (Mitigated)	Not Calculated
		Yes p = 2.5×10^{-5}	6.5×10^{-10}	Below Cat. Freq. Limit (BCFL)	Probabilistic Mean 4.64×10^{-3} rem (Unmitigated)	Not Calculated

* Preclosure period assumed to be 100 years

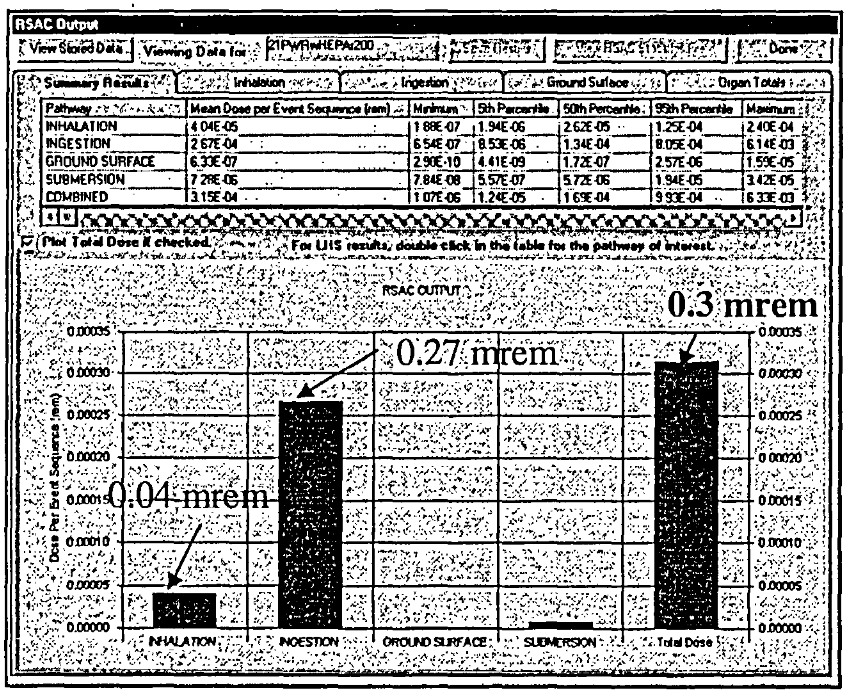
** See backup slide 11 for assumptions

Probabilistic Dose Results (TEDE)

(Screen print from PCSA Tool)

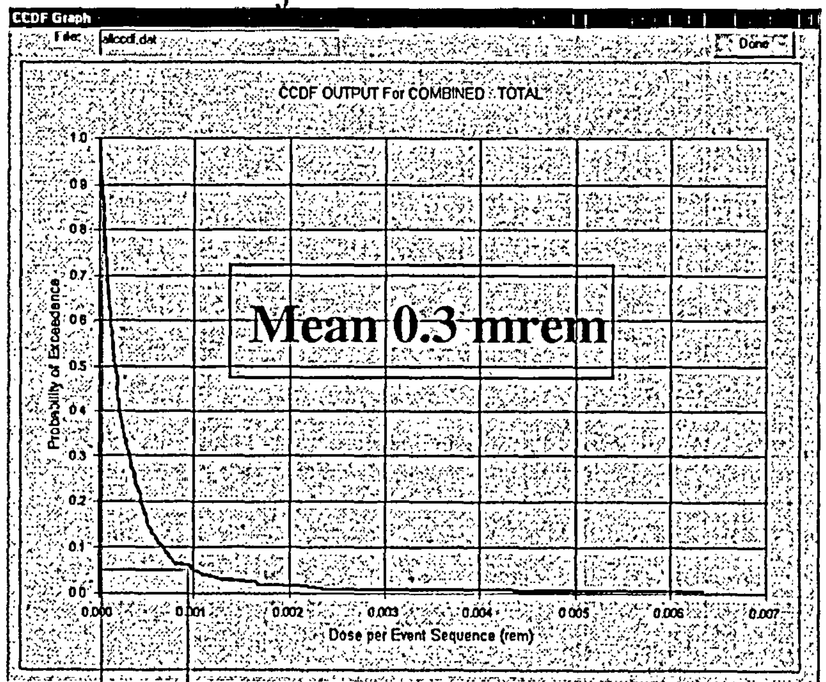
21 PWR Assemblies with HEPA Mitigation

Category 2 Event Sequence; Performance Objective <5 rem



Pathway	Mean Dose per Event Sequence (rem)	Minimum	5th Percentile	50th Percentile	95th Percentile	Maximum
INHALATION	4.04E-05	1.88E-07	1.94E-06	2.62E-05	1.25E-04	2.40E-04
INGESTION	2.67E-04	6.54E-07	8.53E-06	1.34E-04	8.05E-04	6.14E-03
GROUND SURFACE	6.33E-07	2.90E-10	4.41E-09	1.72E-07	2.57E-06	1.59E-05
SUBMERSION	7.28E-06	7.84E-08	5.57E-07	5.72E-06	1.94E-05	3.42E-05
COMBINED	3.15E-04	1.07E-06	1.24E-05	1.69E-04	9.93E-04	6.33E-03

Mean Dose



5th (0.01 mrem)

95th (1 mrem)

CCDF

Example Compliance Analysis for Category 1 Event Sequences

(Screen print from PCSA Tool)

Results Table - Project View Base Case

FunctionalID	EvScen ID	EvSeq ID	EvSeq Freq	Category	Description	Dose, PtEst	Dose, Mean
D.3.2	ADAWP	ADAWP-2	1.87E-01	1	2 PWR With HEPA	1.57E-04	3.00E-05
D.3.2	ADEWP	ADEWP-2	4.60E-02	1	1 PWR With HEPA	7.85E-05	1.50E-05
D.3.2	ADFL	ADFL-2	3.00E-02	1	1 PWR With HEPA	7.85E-05	1.50E-05
D.3.2	ADTC	ADTC-2	2.34E-01	1	2 PWR With HEPA	1.57E-04	3.00E-05
D.3.2	HEADCM	HEADCM-2	3.00E+00	1	1 PWR With HEPA	7.85E-05	1.50E-05
D.4.2	CDHE	CDHE-1	1.10E+01	1	21 PWR No Release	0.00E+00	0.00E+00
D.4.2	CDHE	CDHE-2	1.02E-02	1	21 PWR with HEPA	1.65E-03	3.15E-04
D.5.2	HEWP	HEWP-2	3.60E-01	1	44 BWR with HEPA	1.34E-03	2.57E-04
D.5.2	WPDFL	WPDFL-2	1.02E-02	1	44 BWR with HEPA	1.34E-03	2.57E-04

Dose of each event sequence <15 mrem

Safety Assessment - Category 1 Event Sequences

Frequency-Weighted Annualized Dose

Dose Type: ( ) Point Estimate (•) Probabilistic Mean

Dose Rem / Year

Frequency Weighted Sum: 0.000157124

Normal Release: 0.00006

Total Dose: 0.000217124

Regulatory Limit: [10CFR Part 63.111(a)(2)] 0.015

[Calculate]

Combination of Events

Cutoff Frequency: 1.00E-02

[Calculate]

Run Status

[Done]

Sum of frequency weighted dose <15 mrem/yr

Units: Doses: Rem; Frequency: 1/Year

[SSCIS] [Refresh] [Compliance Assessment] [Edit Record] [Show Report] [Close]

Example Compliance Analysis for Category 2 Event Sequences

(Screen print from PCSA Tool)

Results Table - Project View Base Case

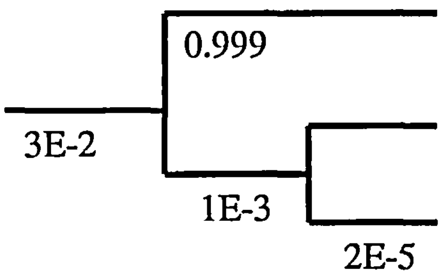
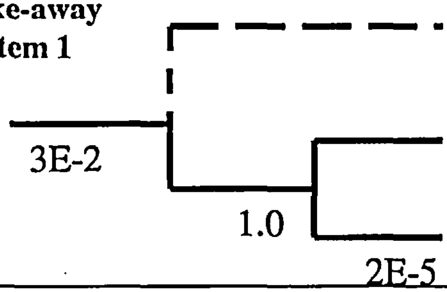
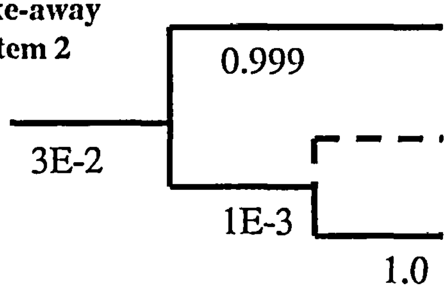
FunctionalID	EvScen ID	EvSeq ID	EvSeq Freq	Category	Description	Dose, PtEst	Dose, Mea
D.3.2	HEADCM	HEADCM-3	6.00E-05	2	1 PWR No HEPA	1.59E-04	2.21E-04
D.4.2	CDEWP	CDEWP-1	1.36E-03	2	21 PWR No Release	0.00E+00	0.00E+00
D.4.2	CDFL	CDFL-1	2.60E-02	2	21 PWR No Release	0.00E+00	0.00E+00
D.4.2	CDFL	CDFL-2	2.80E-05	2	21 PWR with HEPA	1.65E-03	3.15E-04
D.4.2	CDTC	CDTC-1	1.30E-03	2	21 PWR No Release	0.00E+00	0.00E+00
D.4.2	CDTC	CDTC-2	1.40E-05	2	21 PWR with HEPA	1.65E-03	3.15E-04
D.4.2	EQCSR	EQCSR-1	1.52E-03	2	21 PWR No Release	0.00E+00	0.00E+00
D.4.2	EQCSR	EQCSR-2	3.22E-06	2	21 PWR with HEPA	1.65E-03	3.15E-04
D.4.2	EQDCC	EQDCC-1	1.50E-03	2	21 PWR No Release	0.00E+00	0.00E+00
D.4.2	EQDCC	EQDCC-2	1.60E-06	2	21 PWR with HEPA	1.65E-03	3.15E-04
D.4.2	EQDCWP	EQDCWP-1	1.52E-03	2	21 PWR No Release	0.00E+00	0.00E+00
D.4.2	EQDCWP	EQDCWP-2	1.60E-06	2	21 PWR with HEPA	1.65E-03	3.15E-04

Compliance with < 5 rem dose criterion

Units: Doses: Rem
Frequency: 1/Year

SSCIS | Refresh | Compliance Assessment | Edit Record | Show Report | Close

Example Analysis of SSCs Important to Safety

Canister Drop / Safety System 1 / Safety System 2	Event Sequence ID (a)	Event Sequence Category (b)	Event Sequence Frequency (1/yr) (c)	Example Mean Dose (mrem) (d)	Freq.-Wtd Sum of Cat 1 Event Seq. (mrem/yr) (e)	Important to Safety (ITS) (f)
Base line event tree 	CDFL-1	1	3E-2	0	0.22	
	CDFL-2	2	3E-5	0.315		
	CDFL-3	BCFL	6E-10	4.64		
Take-away System 1 						System 1 Not ITS
	CDFL-2A	1	3E-2	0.315	0.23	System 1 ITS if (c) >15 mrem/yr
	CDFL-3A	BCFL	6E-7	4.64		
Take-away System 2 	CDFL-1B	1	3E-2	0	0.22	System 2 Not ITS
	CDFL-3B	2	3E-5	4.64		System 2 ITS if (d) >5000mrem

Risk Analysis

- PCSA Tool provides additional capability to gain risk insight*

- Tool evaluates aggregate risk to a member of the public from entire facility
  - Point-estimate calculation of risk
  - Probabilistic analysis of risk

- Generates risk insights
  - Total risk
  - Largest contributors to the total risk
  - Identifies most likely outcomes for combinations of events either occurring or not occurring

(* Benke, R., B. Dasgupta, B. Sagar, and A. Chowdhury. A METHODOLOGY FOR PRECLOSURE RISK ASSESSMENT FOR A GEOLOGIC NUCLEAR WASTE REPOSITORY. Probabilistic Safety Assessment and Management (PSAM6), Proceedings of the 6th International Conference on Probabilistic Safety Assessment and Management, San Juan, Puerto Rico, June 23-28, 2002, Oxford: Elsevier Science, Ltd. Vol. I, pp. 983-988. 2002)

Future Work

- Develop PCSA Tool Version 3.0 in Fiscal Year 2004
  - Incorporate capability for assessing worker dose
  - Enhance capability to identify SSCs important to safety

- Perform Software Validation for PCSA Tool Version 3.0 in Fiscal Year 2004

- Continue Preclosure Safety Analyses in Fiscal Year 2004

Summary

- PCSA Tool will be used to review selected portions of DOE preclosure safety analysis
- Tool provides staff with independent analysis capability
- Staff conducted simplified analysis of a conceptual Dry Transfer Facility using PCSA Tool
- Staff will continue to conduct preclosure safety analyses using PCSA Tool
- PCSA Tool enhancements identified, and work planned for Fiscal Year 2004

Backup Slides

Frequency Categorization

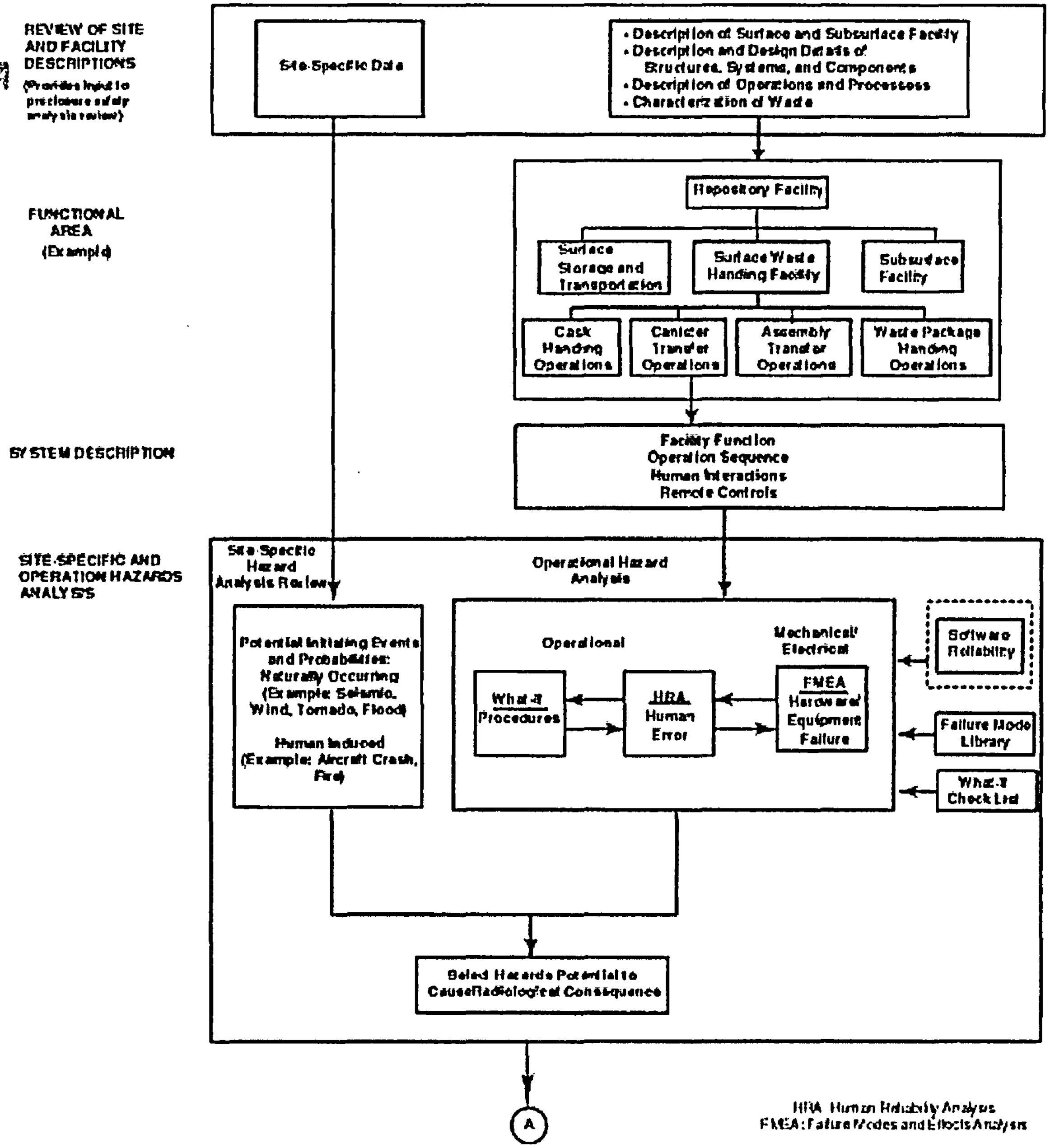
- Category –1
  - Event sequences that are expected to occur one or more times before permanent closure

- Category –2
  - Event sequences that have at least 1 chance in 10,000 of occurring before permanent closure

Compliance Analysis

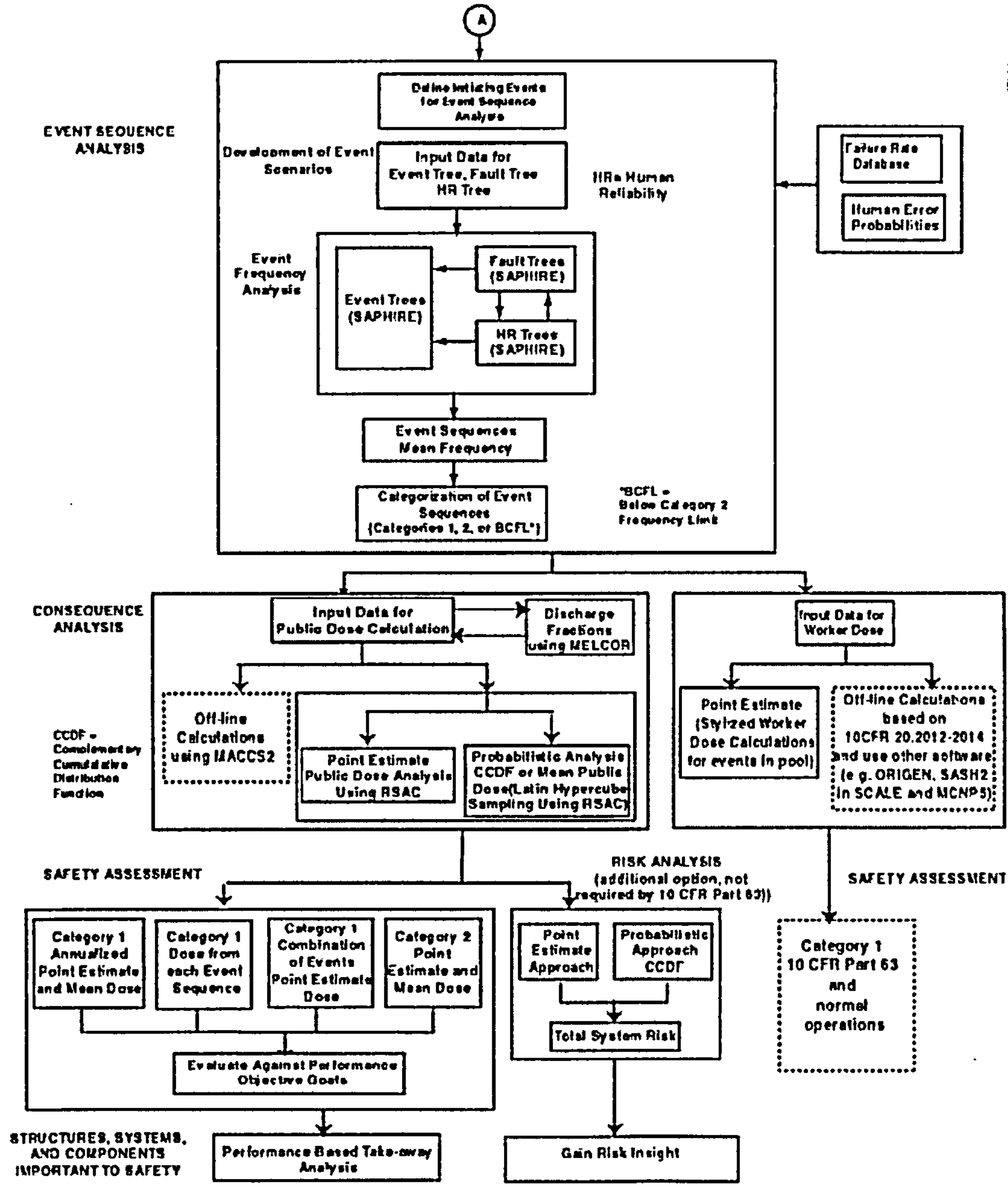
- Public safety
  - Category 1 event sequences: < 15 mrem/year
    - Dose from each event sequence
    - Frequency-weighted sum of annual doses
    - Summation of dose from combination of multiple event sequences occurring in a single year
  - Category 2 event sequences: < 5 rem TEDE for each event sequence (plus other organ dose limits)
  - Risk-informing the review
    - Identifies individual Category 1 event sequences that contribute the most to the frequency-weighted sum of annual doses
- Worker safety (10 CFR Part 20 limits)

PCSA Structures and Modules

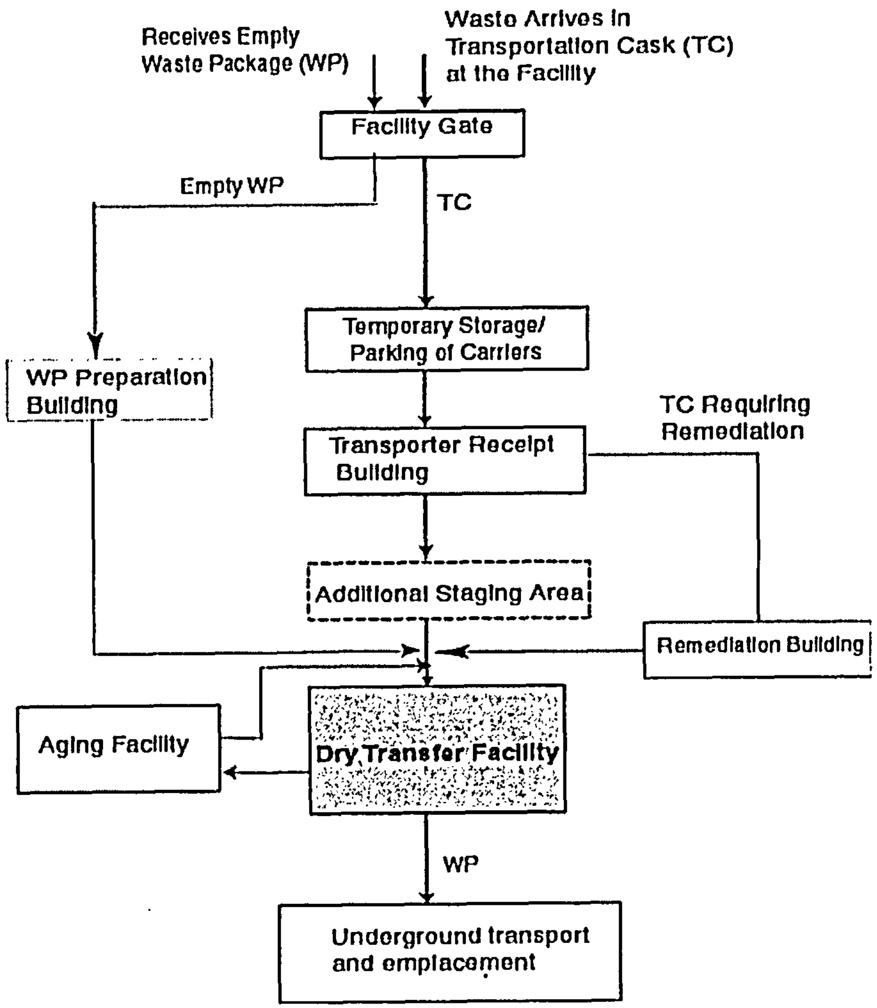


HRA: Human Reliability Analysis
FMEA: Failure Modes and Effects Analysis

PCSA Structures and Modules (Continued)



Conceptual Surface Facility



Identification of Initiating Events

Functional Area	Hazards	Initiating Events
D.3.2	Assembly Drop	Failure of Assembly Transfer Machine
	Assembly Drop	Human Error
D.4.2	Canister Drop	Failure of Bridge Crane
	Canister Drop	Human Error
	Handling Equipment drop on Canister	Yoke detach from Bridge Crane
D.5.2	Unsealed WP drop and tip-over	Failure of Bridge Crane
	Unsealed WP drop	Human Error

Failure Data

Equipment/System	Failure Rate/Probability	Source
Assembly Transfer Machine	1.8×10^{-5} Drops/lift	Assumed
Bridge Crane	1.7×10^{-5} Drops/lift	Fault Tree
Handling Equipment Drop	1.9×10^{-6} Drops/lift	Fault Tree
Human Error	0.012	Fault Tree
Weld defect in Canister	1×10^{-3}	Assumed
HVAC/HEPA	2.5×10^{-5}/day	Assumed

Event Scenarios

Functional Area	Event Scenario Identifier	Initiating Event ⇒ Breach ⇒ HVAC/HEPA (ATM = Assembly Transfer Machine ; SFA = Spent Fuel Assembly)	Initiating Event Identifier	Material at Risk (Number and type)
D.3.2	ADTC	ATM drops SFA onto another SFA in transportation cask	ATMFL1	2 PWR
	ADFL	ATM drops SFA on DTF floor SFA during transfer	ATMFL2	1 PWR
	ADEWP	ATM drops SFA in empty WP during SFA lowering	ATMFL3	1 PWR
	ADAWP	ATM drops SFA on to another SFA during lowering in WP	ATMFL4	2 PWR
	HEADCM	Assembly damaged due to Human Error	HEAD	1 PWR
D.4.2	CDTC	Drop of Canister into Transportation cask due to failure of Bridge Crane	BCFLMH1	21 PWR
	CDFL	Drop of canister on Staging Rack	BCFLMH2	21 PWR
	CDEWP	Drop of Canister into empty WP	BCFLMH3	21 PWR
	WQCSR	Canister drop due to Human Error See Slide No. 11	HHECD	21 PWR
	EQDCSR	Handling equipment drop on Canister in staging rack	EQDP1	21 PWR
	EQDCC	Handling equipment drop on Cask with canister in it	EQDP2	21 PWR
	EQDCWP	Handling equipment drop on WP with Canister	EQDP2	21 PWR
D.5.2	WPDFL	Drop unsealed WP and tipover while lifting onto welding turntable	IWPDFL	44 BWR
		Human error	HHEWP	44 BWR

Initiating Event Frequencies

Functional Area	Initiating Event	Initiating Event Identifier	No of lifts	Failure Rate	Initiating Event Frequency /yr
D3.2 Assembly Transfer	Failure of Assembly Transfer Machine	ATMFL1 ATMFL2 ATMFL3 ATMFL4	12800 12800 12800*0.2 12800*0.8	1.8E-5 (1/8)*1.8e-5 1.8e-5 1.8e-5	0.234 0.028 0.046 0.187
	Human Error	HEAD	12800	0.012	154
D 4.2 Canister Transfer	Failure of Bridge Crane	BCFLMH1 BCFLMH2 BCFLMH3	800 2x800 800	1.7e-5 1.7e-5 1.7e-5	1.3e-2 2.6e-2 1.3e-2
	Human Error	IHECD	2x800	0.007	11.2 See Slide No. 11
	Handling Equipment Drop	EQDP1 EQDP2 EQDP2	2x800 800 800	1.9e-6 1.9e-6 1.9e-6	3e-3 1.5e-3 1.5e-3
D 5.2 Welding Cell	Failure of Bridge Crane	IWPDFL	600	1.7e-5	1.02e-2
	Human Error	IHEWP	600	0.006	3.6

Number of Assemblies Handled: 12,800 /yr
Number of Canisters handled: 800 /yr

Consequence Analysis Assumptions for Public Dose

- Deterministic Analysis
  - Deterministic calculation using best estimate parameter values where available
  - Hot cell structure assumed to provide containment
  - Breach of all rods for each assembly damaged
  - Dose to member of public located downwind at closest offsite distance of 11 km
  - No credit given to breached canisters to mitigate the radionuclide release from the assemblies
- Probabilistic Analysis
  - Probabilistic calculations for the same assumptions as described for deterministic dose calculation
  - 200 realizations using the PCSA Tool defaults
  - Release fractions were sampled with distributions based on the values in the literature

Risk Analysis Capability

(Screen Shots from PCSA Tool)

Deterministic Results

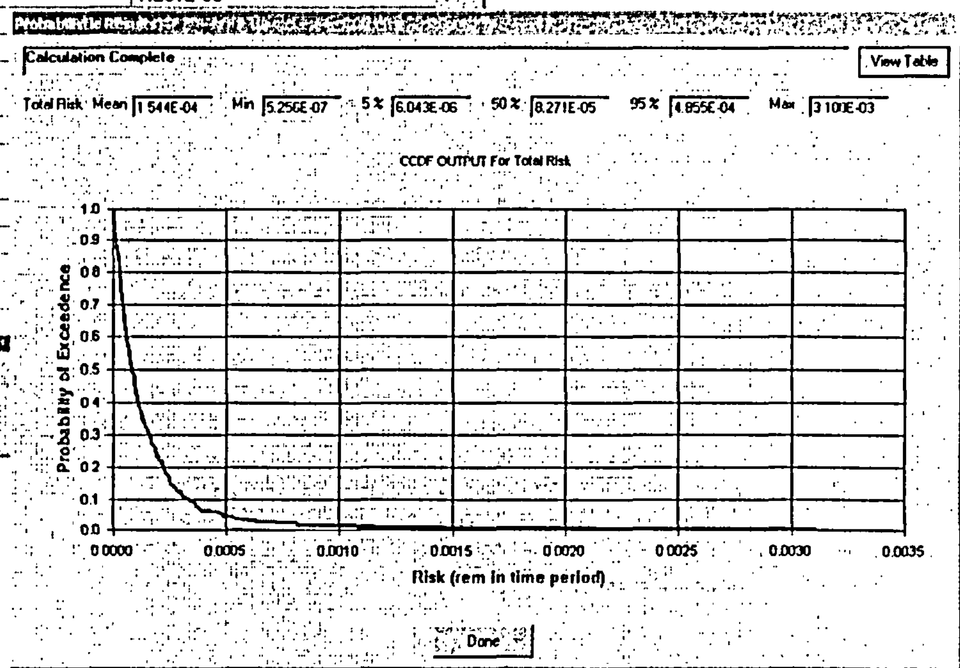
Calculation Complete

Outcome State	Probability	Consequence (rem)	Risk (rem in time period)
++--+--+----+-	5.693E-03	9.990E-04	5.688E-06
+-+-+--+----+-	3.534E-03	1.002E-03	3.540E-06
+--++--+----+-	3.128E-02	1.098E-03	3.433E-05
+---+-++----+-	3.294E-04	9.357E-04	3.082E-07
+---+--++---+-	1.646E-04	9.357E-04	1.540E-07
+---+--+-+--+-	3.682E-04	9.204E-04	3.389E-07
+---+--+--+-+-	1.840E-04	9.204E-04	1.693E-07
+---+--+---++-	1.840E-04	9.204E-04	1.693E-07
+---+--+----++	1.234E-04	2.255E-03	2.782E-07
-++-+--+----+-	8.088E-04	9.099E-04	7.359E-07
-+-++--+----+-	7.159E-03	1.006E-03	7.201E-06
--+++--+----+-	4.444E-03	1.008E-03	
---++-++----+-	4.142E-04	9.425E-04	
---++--++---+-	2.070E-04	9.424E-04	
---++--+-+--+-	4.630E-04	9.272E-04	
---++--+--+-+-	2.314E-04	9.272E-04	
---++--+---++-	2.314E-04	9.272E-04	
---++--+----++	1.551E-04	2.262E-03	
+++-+--+----+-	1.664E-04	1.082E-03	
++-++--+----+-	1.473E-03	1.178E-03	
+-+++--+----+-	9.140E-04	1.181E-03	
-++++--+----+-	2.092E-04	1.089E-03	
Total Risk			

Done

Output Showing Deterministic Results

Output Showing Probabilistic Results



October 22, 2003

MECHFAIL: A TPA Code Module for Evaluating Engineered Barrier Performance Under Mechanical Loading Conditions

Presented by:

Doug Gute

Participants:Goodluck Ofoegbu, Fernand Thomassy, Sui-Min Hsiung, George Adams, Amitava Ghosh, Biswajit Dasgupta, Asadul H. Chowdhury, and Sitakanta Mohanty

NRC Program Manager: Mysore Nataraja

CNWRA Element Manager: Asadul H. Chowdhury

October 22, 2003

146th ACNW Meeting

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Presentation Outline

- Objective
- Overview of the Engineered Barrier System Components
- Risk Insights
- Overview of the MECHFAIL Module
- Characterization of Mechanical Loads
  - Seismic
  - Static Rockfall (Discussed in Dr. Ofoegbu's Presentation)
  - Dynamic Rockfall (Discussed in Dr. Ofoegbu's Presentation)
- Drip Shield Response to Mechanical Loads
- Waste Package Response to Mechanical Loads
- MECHFAIL Module Output to Other TPA Modules
- Closing Observations

Objective

- Stochastically Estimate the Number of Drip Shield and Waste Package Failures Attributable to Seismic and Rockfall Events
  - Approximate Temporal and Spatial Variations
  - Assess Accumulated Damage
  - Establish Risk Significant Failure Mechanisms

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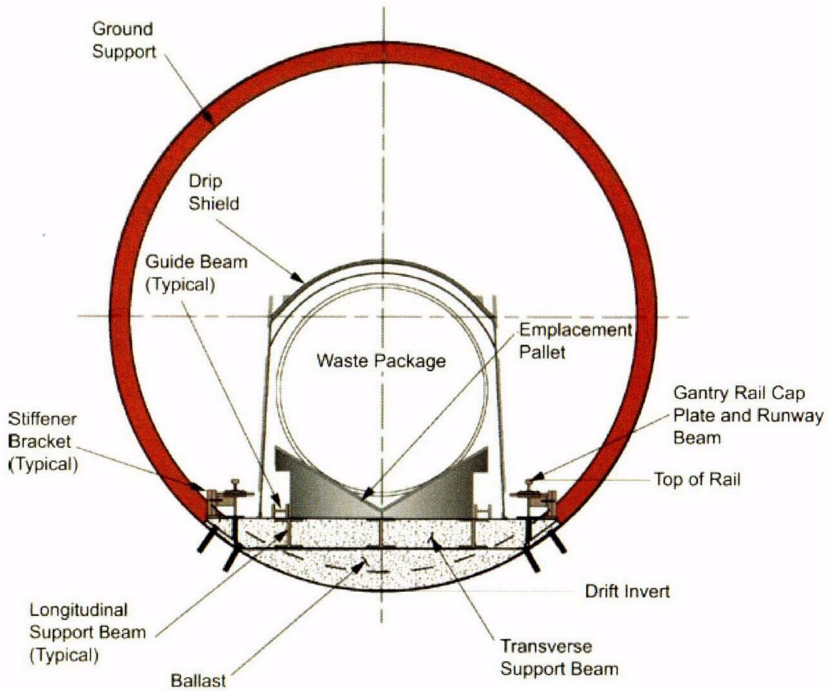
Engineered Barrier System Components



- Waste Package
- Drip Shield
- Invert
- Waste Package Pallet Support
- Spent Nuclear Fuel Cladding

C01

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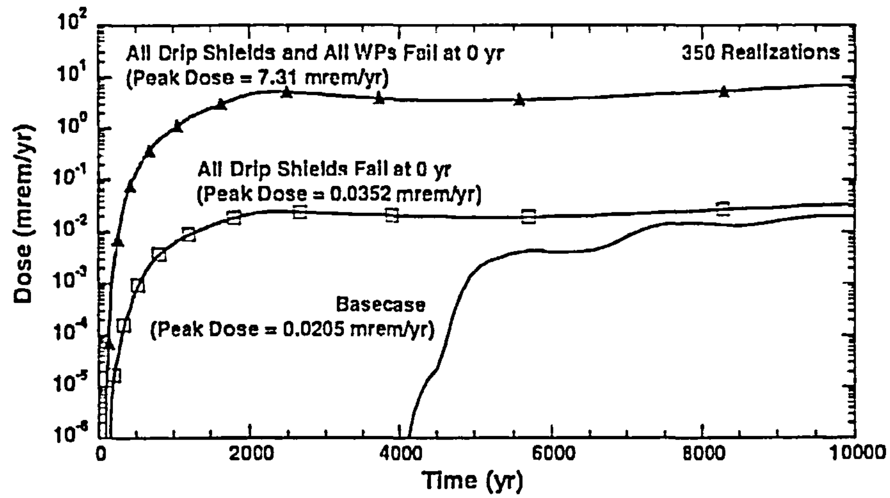
Risk Insights

- A TPA Analysis Indicates that Removal of the Drip Shield at the Time of Repository Closure Will Increase the Expected Dose by Less Than 75% (i.e., less than a factor of 2) Relative to the Nominal Scenario, Which is Still at Least Two Orders of Magnitude Below the Regulatory Limit
- When Both the Drip Shield and Waste Package Are Removed at the Time of Repository Closure the Calculated Dose Increases by Two Orders of Magnitude Relative to the Nominal Scenario
- The Potential Increase of Seepage Into the Drift Caused by the Presence of Rockfall Rubble Was Not Considered in These TPA Analyses



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Overview of the MECHFAIL Module

- Several Abstractions Support Assessment of the Effects of Mechanical Loads on the Engineered Barrier Subsystem
  - The Number of Seismic Events Expected During the Regulatory Period, Their Occurrence Times, and the Associated Ground Motion Magnitudes
  - The Spatial and Temporal Distributions of Rockfall Loads, Both Static and Dynamic
  - The Mechanical Effects of Seismic and Rockfall Loads on the Engineered Barrier System (i.e., the Drip Shield and Waste Package), Including Potential Interactions Between Individual Components
  - Applicable Failure Mechanisms and Their Respective Failure Criteria
    - Buckling
    - Plastic Collapse (i.e., Continuum Mechanics Failure Criteria)
    - Fracture (i.e., Fracture Mechanics Failure Criteria)
    - Creep

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Overview of the MECHFAIL Module

- Mechanical Loads Not Accounted for in the MECHFAIL Module
  - Faulting
    - Not Expected to Cause Significant Drip Shield and Waste Package Damage
    - The Fault-Setback Distance (From Known Faults) is Used as an Additional Mitigative Design Feature
    - Very Small Percentage of Drip Shields and Waste Packages are Expected to be Affected
  - Igneous Intrusion
    - Addressed in the VOLCANO TPA Code Module

Overview of the MECHFAIL Module

- Material Degradation and Corrosion Processes (Including Stress Corrosion Cracking), Fabrication Flaws, Fabrication Residual Stresses and Loss of Ductility (Caused by Quenching, Welds, and Shrink Fits), and Hydrogen Embrittlement are Not Accounted for in the MECHFAIL Module

- Strain Rate Effects on Material Behavior Have Not Been Considered

  — High Strain Rates Typically Increase Yield Stress While Decreasing Ductility

- Accumulated Damage Accommodated by Summing the Plastic Strains Caused by Individual Events

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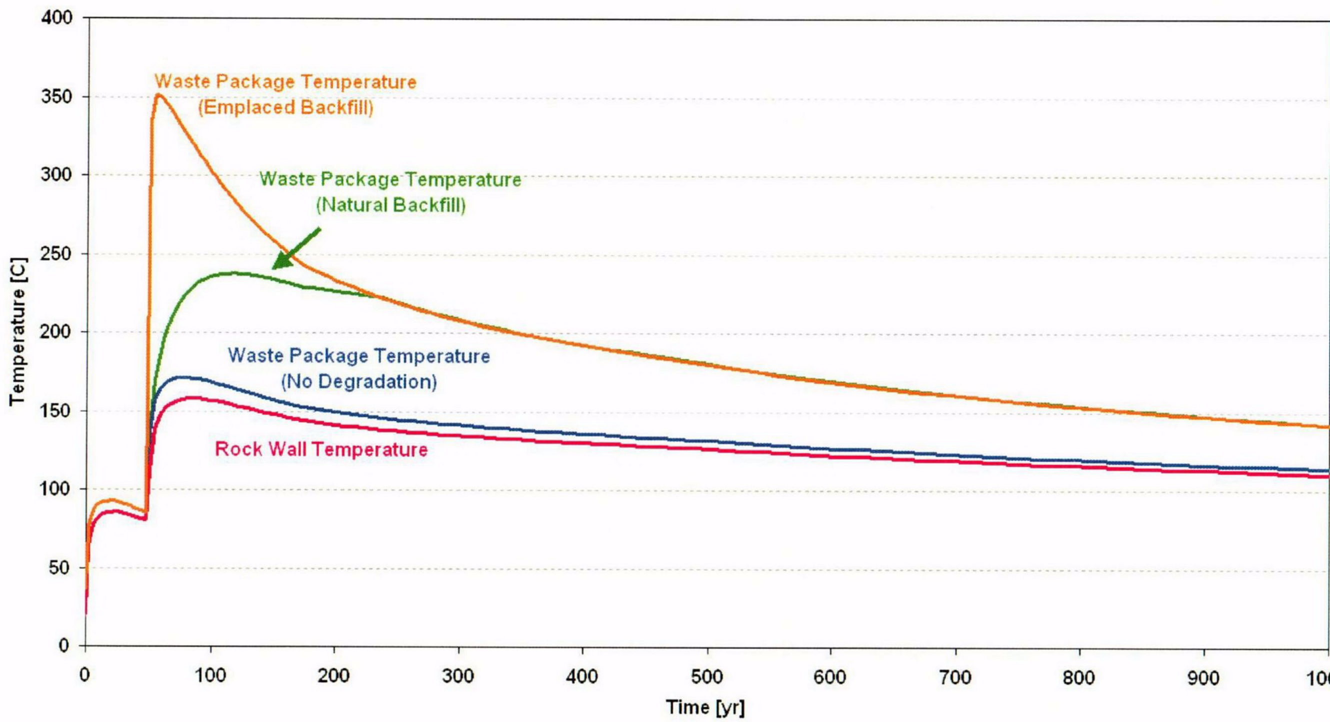
Overview of the MECHFAIL Module

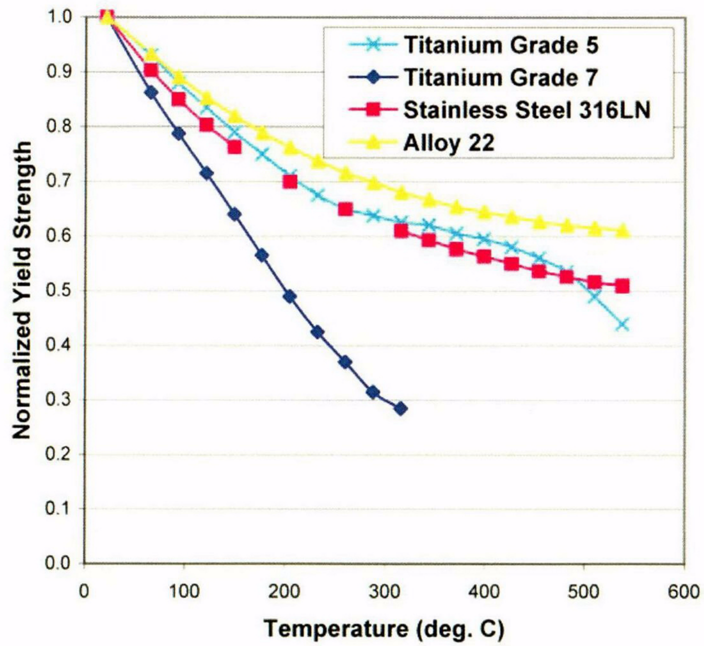
- Varying Temperatures and Their Effects on Mechanical Properties are Not Accounted for (Assumed Fixed Temperature of 150 °C [302 °F])

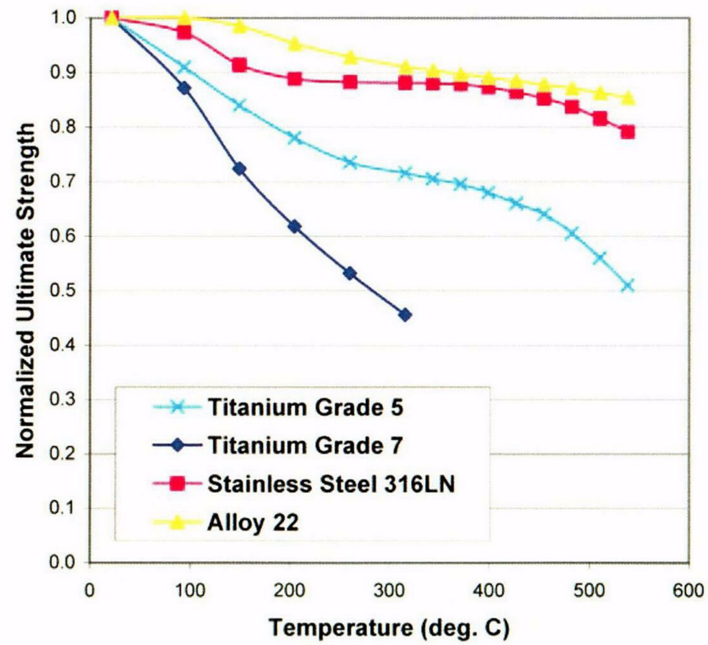


C02

Overview of the MECHFAIL Module

- Temperature Effects on the Mechanical Properties of the Engineered Barrier System Materials





C03

Characterization of Seismic Loads

- The TPA Code Uses the DOE Generated Seismic Hazard Curve for a Hypothetical Rock Outcrop Reference Located on the Surface
- A Given Seismic Event is Characterized in Terms of the Mean Peak Horizontal Ground Acceleration
- The Seismic Hazard Curve in the Low Annual Frequency of Exceedance Regime (I.e., Less Than 10^{-6}/yr) Has Yet to be Finalized
- The Current Seismic Hazard Curve Sampling Methodology is Expected to be Sufficient for Assessing the Potential Effects of Relatively High-Probability Ground Motions
- Low-Probability Seismic Events will Likely Have to be Assessed as Unique Scenarios (Similar to Igneous Events)

Drip Shield Response to Seismic Loads

- The Response of the Drip Shield to Seismic Ground Motion Time Histories Has Yet to be Assessed

- Eigenvalue Analyses Indicate the Drip Shield has Several Natural Frequencies Below 33 Hz (The Effect of Accumulated Rubble Was Not Considered)

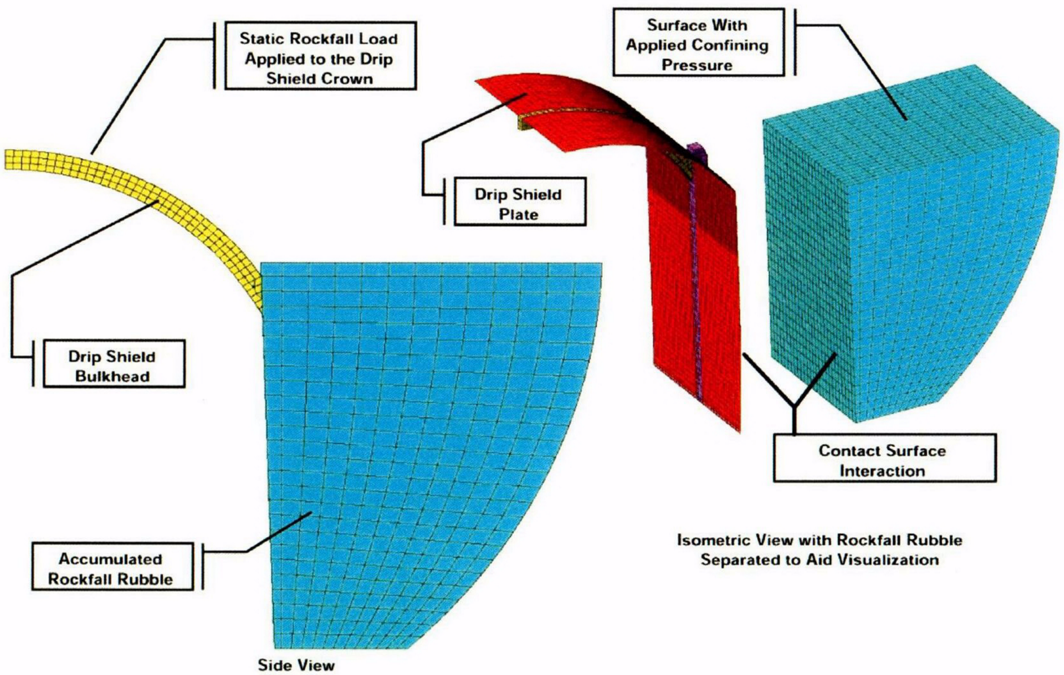
  - The Vast Majority of the Energy Associated with a Seismic Event can be Attributed to the Generated Ground Waves with Frequencies Less Than 33 Hz

  - The Number of Drip Shield Natural Frequencies Below the 33 Hz Threshold is Strongly Dependent on the Assumed Drip Shield Base Constraints (i.e., Free Standing, Simply Supported, or Cantilevered)

  - Structural Natural Frequencies that Fall Within the Excitation Frequency Spectrum (i.e., Design Spectrum) Indicate that Dynamic Amplification May Occur

Drip Shield Response to Static Rockfall Loads

- Process Level Model



C04

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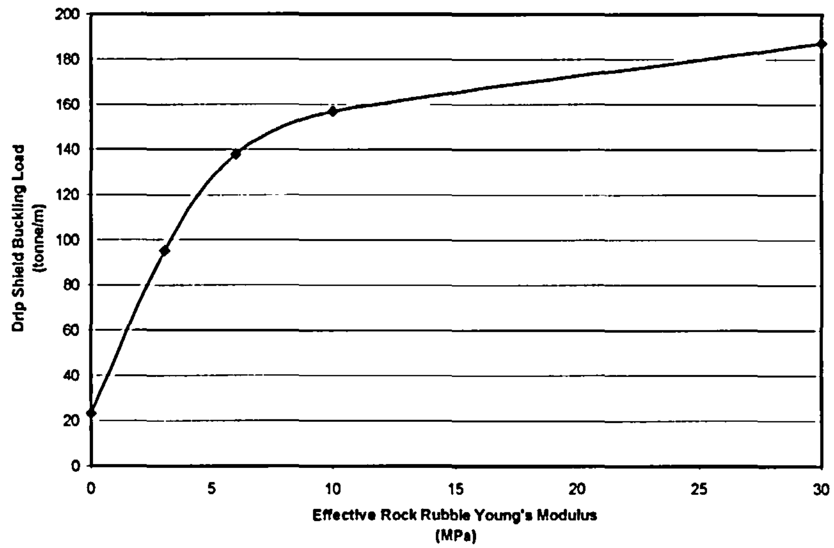
Drip Shield Response to Static Rockfall Loads (Continued)

- Process Level Model Results
  - A Range of Rockfall Rubble Elastic Moduli were Evaluated in the Process Level Model To Assess the Potential Effects of the Rubble on the Drip Shield Structural Support



146th ACNW Meeting
October 22, 2003

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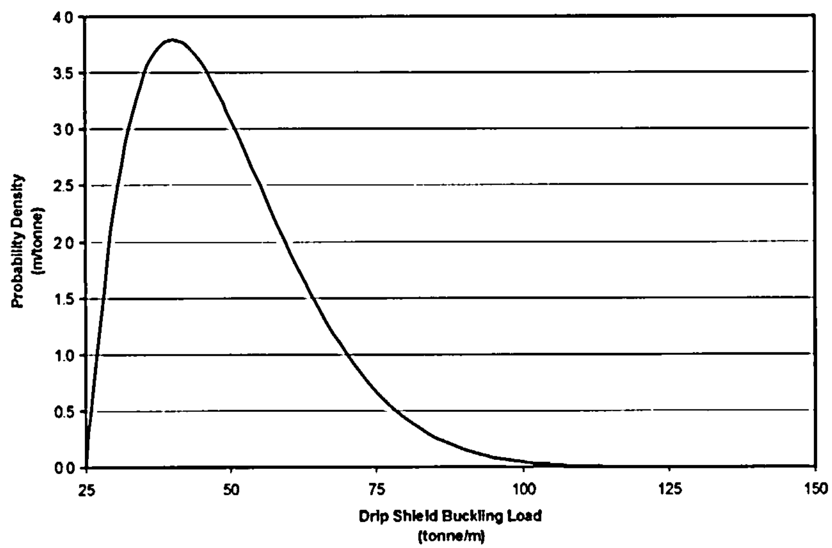
Drip Shield Response to Static Rockfall Loads (Continued)

- Process Level Model Abstraction
  - A Beta Distribution is Used to Assign the Drip Shield Buckling Load
  - The Creep Threshold Load is Strongly Correlated with the Buckling Load
  - Static Rockfall Loads are Adjusted to Account for Increased Effective Weight During Seismic Events



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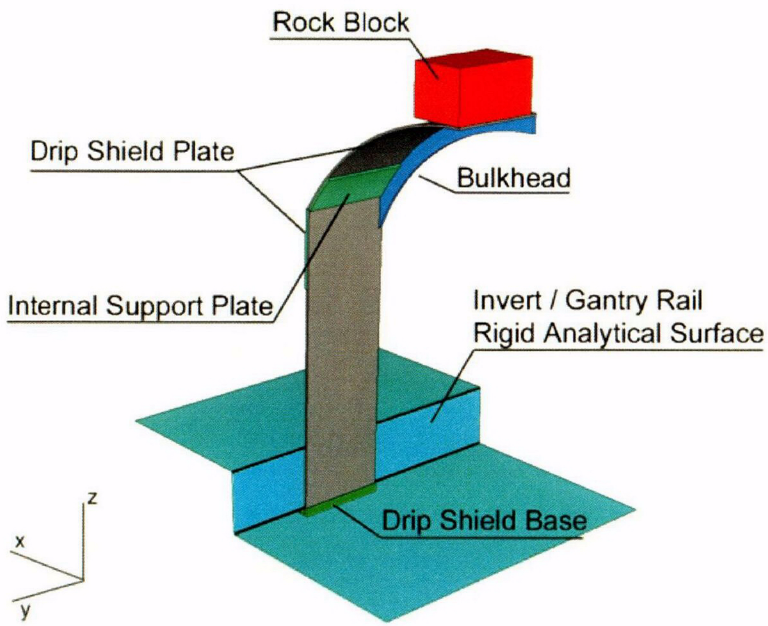
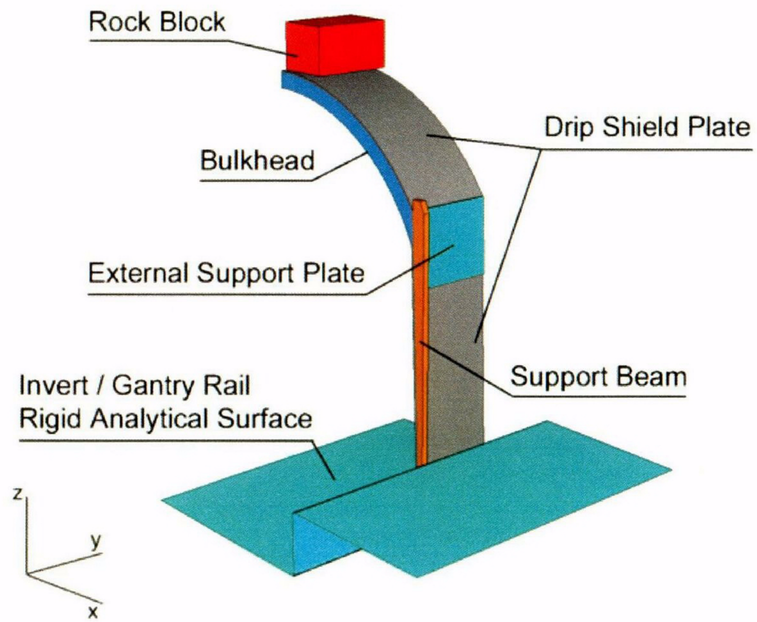
Drip Shield Response to Dynamic Rockfall Loads

- Process Level Model





C05

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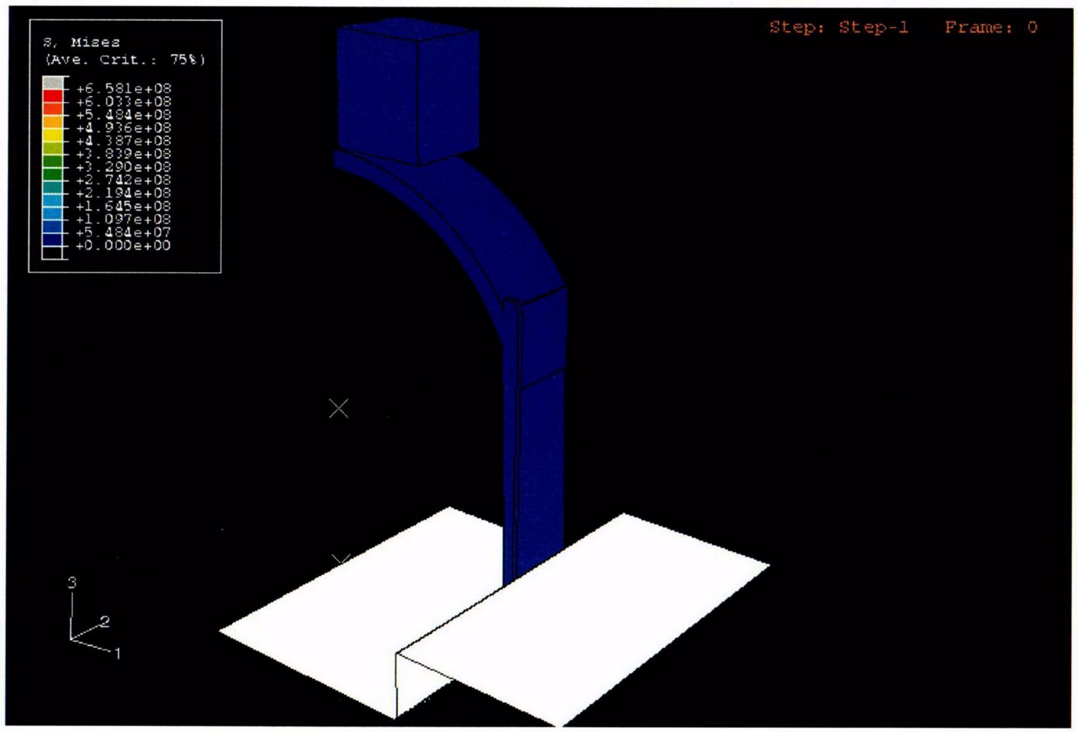
Drip Shield Response to Dynamic Rockfall Loads (Continued)

- MECHFAIL Module Abstraction Assumptions for Dynamic Rockfall Loads
  - Dynamic Rockfall Loads have no Affect on the Drip Shield after 0.5 m [1.6 ft] of Rubble has Accumulated Above the Drip Shield Crown
  - Dynamic Rock Block Impacts Only Occur in the Middle Nonlithophysal Rock Unit (Which Will be Somewhere in the Range of 15 to 25 percent of the Repository Footprint)

Drip Shield Response to Dynamic Rockfall Loads (Continued)

- Drip Shield Displacement, Velocity, Equivalent Plastic Strains, and Von Mises Stress Abstracted as Functions of Rock Block Mass and Fall Height



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Waste Package Response to Seismic and Rockfall Loads

- Waste Package Response to Seismic Loads
  - The Response of the Waste Package to Seismic Ground Motion Time Histories Has Yet to be Assessed
  - Eigenvalue Analyses Currently Underway
- Waste Package Response to Rockfall Loads (Both Static and Dynamic)
  - No Direct Rockfall Loads Should be Experienced by the Waste Package (DOE has Committed to Designing the Drip Shield to Achieve this Goal)

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Waste Package Response to Seismic and Rockfall Loads (Continued)

- Drip Shield and Waste Package Interactions
  - Static Rockfall Loads
    - Process Level Model Is Still Under Development
    - Preliminary Qualitative Assessment Indicates the Potential for Significant Plastic Straining of the Waste Package Outer Barrier if the Drip Shield Deflects Sufficiently Far Enough to Transfer Static Rockfall Loads to the Waste Package
  - Dynamic Rockfall Loads
    - Drip Shield and Waste Package Interactions Arising from Dynamic Rockfall Loads are a Relatively Low Priority Because a Small Percentage of Waste Packages Could be Affected

MECHFAIL Module Output to Other TPA Modules

- Percentage of Drip Shield Failures on a TPA Subarea and Time Step Basis
- Percentage of Waste Package Failures on a TPA Subarea and Time Step Basis (Abstractions are Still Under Development)
- The Extent of Drift Degradation on a TPA Subarea and Time Step Basis (Both Rock Rubble and Drift Degradation Heights)

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Closing Observations

- Preliminary MECHFAIL Module Results Indicate that, on Average, 75 percent of the Drip Shields Buckle Under Static Rockfall Loads Within 500 yrs After Cessation of Maintenance of the Ground Support System
- Degradation of the Invert May Increase Drip Shield Interactions With the Waste Package During Seismic Events and/or When Subjected to Rockfall Loads
- The Drip Shield and Invert Designs are Being Reevaluated by DOE
- MECHFAIL Abstractions May Have to be Updated to Reflect Design Changes

EVALUATION OF ROCKFALL EFFECTS IN POSTCLOSURE PERFORMANCE ASSESSMENT

Presented by: Goodluck I. Ofoegbu
Phone: (210) 522-6641, email: gofoegbu@swri.org

Participants: B. Dasgupta, A. Ghosh, G.D. Gute, and S. Hsiung

NRC Program Manager: M.S. Nataraja
CNWRA Element Manager: A.H. Chowdhury

October 22, 2003
146th ACNW Meeting

NRC Staff Objectives in Rockfall Analysis

- Preclosure Safety Analysis
  - Determine if the emplacement drifts are sufficiently stable to provide reasonable assurance of safe operation of repository until permanent closure
- Postclosure Performance Assessment
  - Evaluate mechanical loading of the engineered barrier system
    - Dynamic rock-block impact
    - Accumulated rockfall rubble
  - Evaluate changes in emplacement drift configuration that could affect the waste-package environment
- Focus of Presentation
  - Rockfall analysis for postclosure performance assessment

Rockfall Analysis for Postclosure Performance Assessment

- Probability of Occurrence
  - Dynamic rock-block impact
  - Accumulated rockfall rubble
- Mechanical Loading from Accumulated Rockfall Rubble
- Long-Term Configuration of Emplacement Drifts
- Drift Degradation Rates
- Status of Issue Resolution

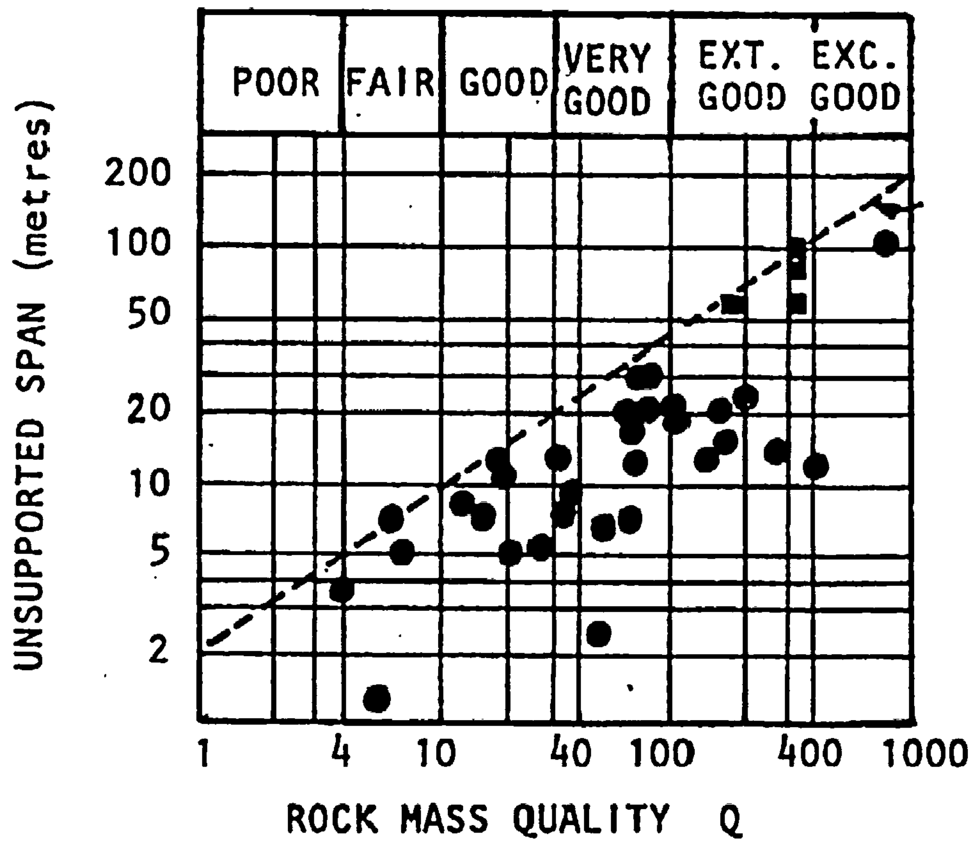
Dynamic Rock-Block Impact on Drip Shield

- Lower Lithophysal Stratigraphic Unit
  - Rock-block impact on drip shield is not a concern within this rock unit because potential individual rock blocks are generally not large enough to cause any damage to the drip shield
- Middle Nonlithophysal Stratigraphic Unit
  - Potential for dynamic rock-block impact
    - 60% of blocks < 1.0 m^3
    - 85% of blocks < 2.0 m^3
  - Effect of rock-block impact mitigated
    - 15-25 percent of emplacement area may be affected
    - Drip shield may be buried in rubble

Occurrence of Drift Degradation and Accumulated Rockfall Rubble

- Emplacement Drifts Are Expected to Experience Rockfall and Accumulation of Rockfall Rubble After Permanent Closure
  - Documented engineering experience
    - Design of underground openings
    - Behavior of abandoned underground mine openings
  - Previous CNWRA analyses performed for NRC staff, which indicate that emplacement drifts need engineered ground support for stability
- DOE Developed Information Support a Similar Observation

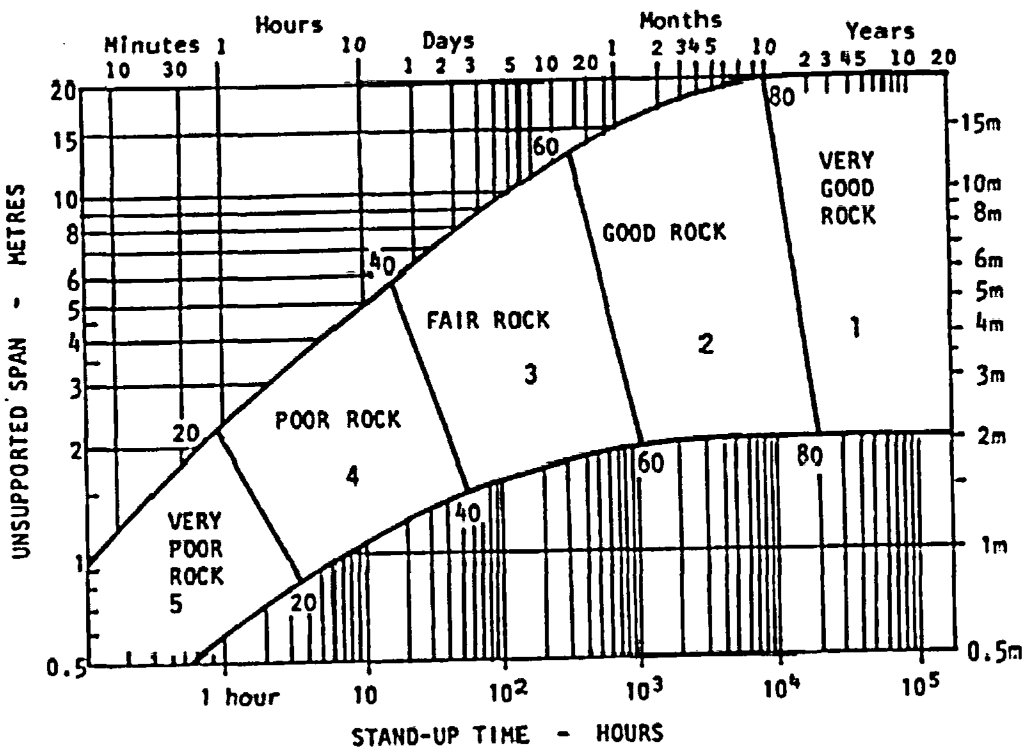
Stability of Unsupported Underground Openings



Hoek E. and E.T. Brown. Underground Excavations in Rock, p. 288. Institution of Mining and Metallurgy. 1980.

- Based on a survey of existing unsupported openings
- Generally used to guide support-installation decisions
- DOE not likely to use Q index for rock characterization at Yucca Mountain

Stability of Unsupported Underground Openings

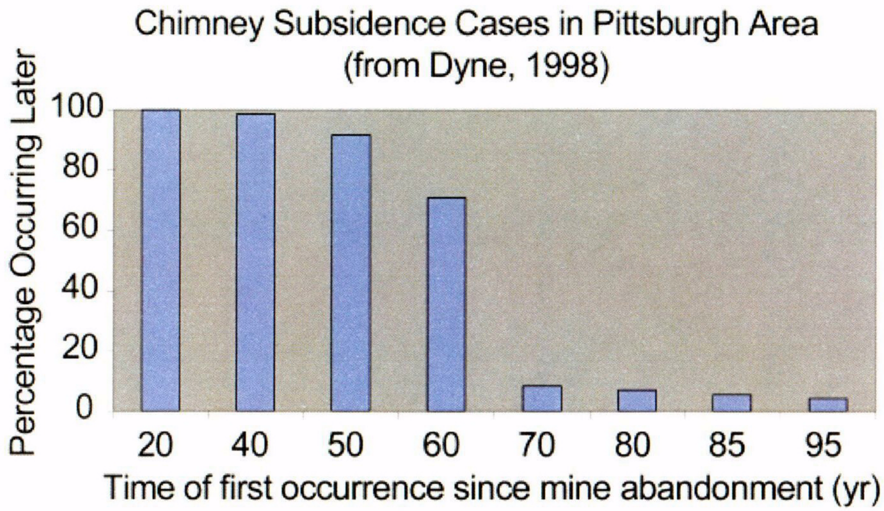


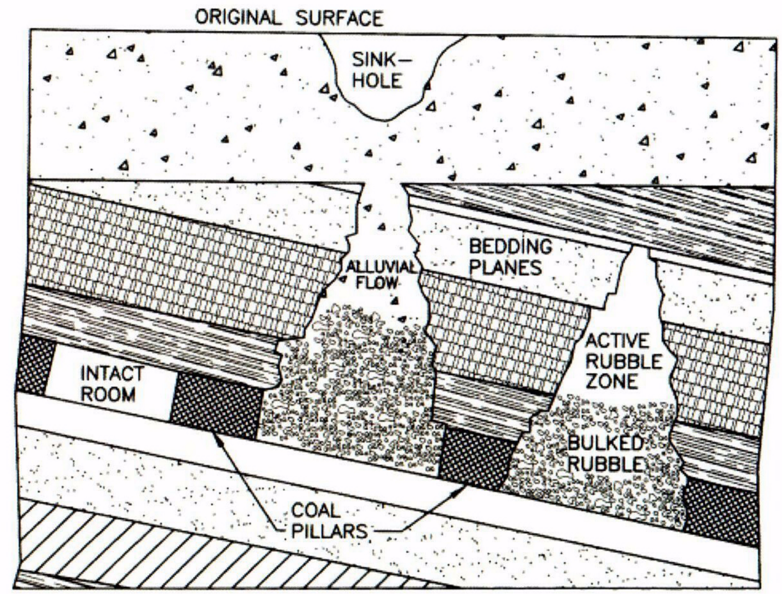
Hoek E. and E.T. Brown. Underground Excavations in Rock, p. 25. Institution of Mining and Metallurgy. 1980.

- Based on case histories on the stability of underground openings
- Generally used to guide support-installation decisions
- DOE not likely to use this rock-quality index for mechanical characterization of Yucca Mountain rock

Behavior of Abandoned Underground Mine Openings

- Sinkholes Occurring At the Ground Surface Above Abandoned Mines Result from Collapse of Underground Mine Openings

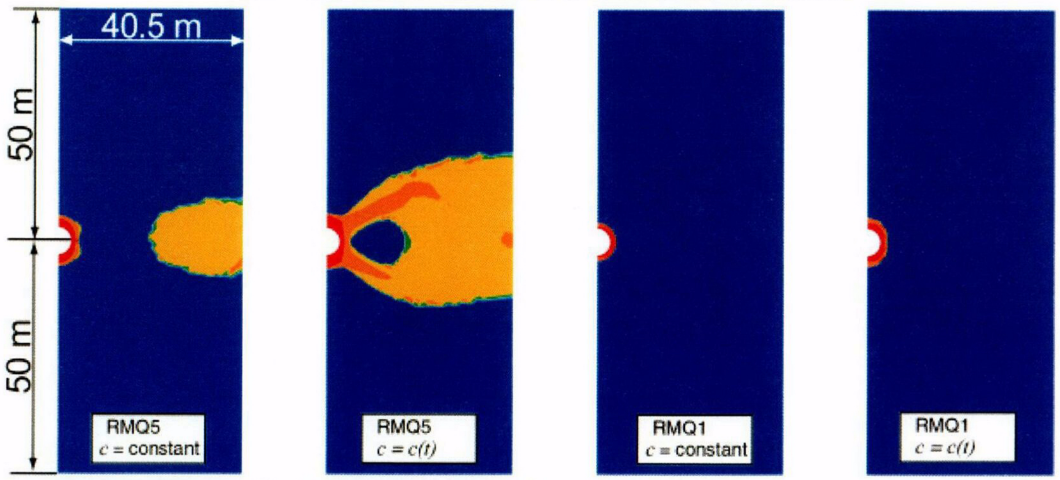


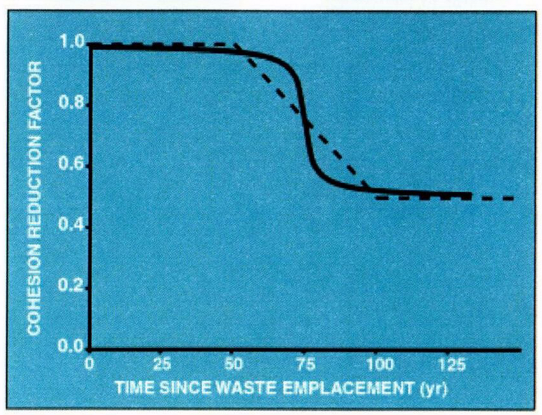


C07

Potential for Drift Degradation (Based on CNWRA Analyses)

INELASTIC STRAIN DISTRIBUTIONS AROUND UNSUPPORTED DRIFTS
AT 150 YR AFTER WASTE EMPLACEMENT

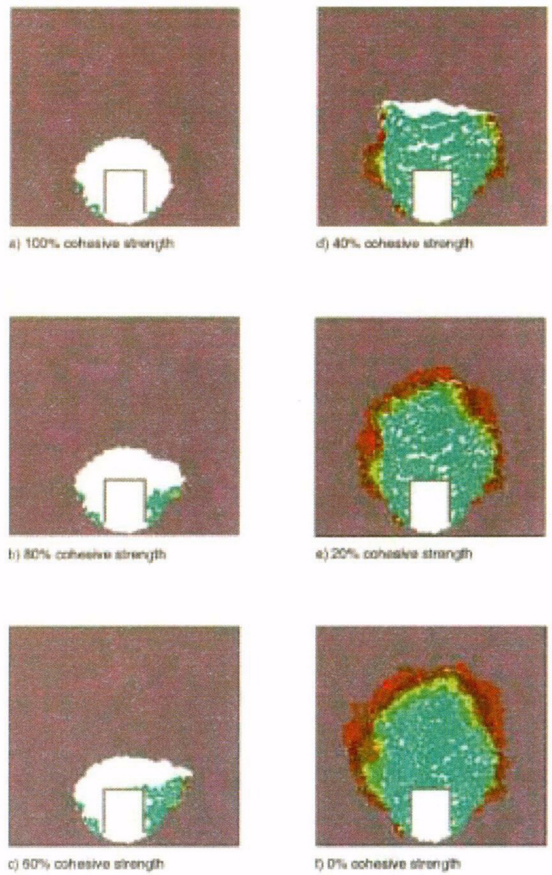




	RMQ1	RMQ5
YOUNG'S MODULUS (GPa)	7.8	32.6
FRICTION ANGLE (degree)	27.5	34.4
INITIAL COHESION (MPa)	2.82	5.08

- Based on EDA II Design Without Ventilation
- Rock Mass Properties Based on DOE Site Recommendation Information
- Results Indicate Ground Support Would Be Needed to Maintain Stable Openings for the Design Evaluated

Potential for Drift Degradation
(Based on DOE Analyses)



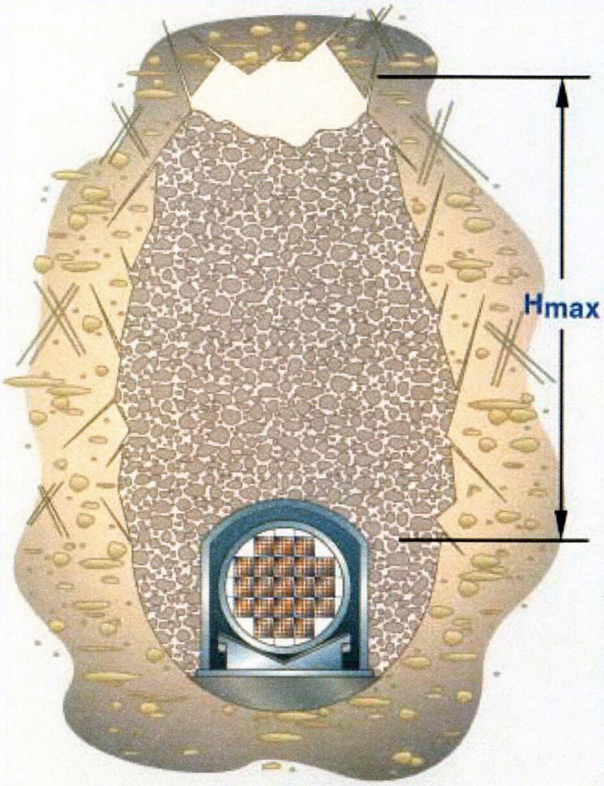
YUCCA MOUNTAIN PROJECT

BSC Presentations_RDTME Tech Exchange_YMDamjanac_05/6-8/03 48 of 52

- Analysis Based On Discontinuum Model With Large Number of Contacting Discrete Blocks (Voronoi Polygons)
- Rock Cohesion Reduced in Five 20% Steps from 100% to Zero
- Results Indicate Openings Without Ground Support Would Experience Rockfall as Rock Strength Degrades

C09

Amounts of Accumulated Rockfall Rubble



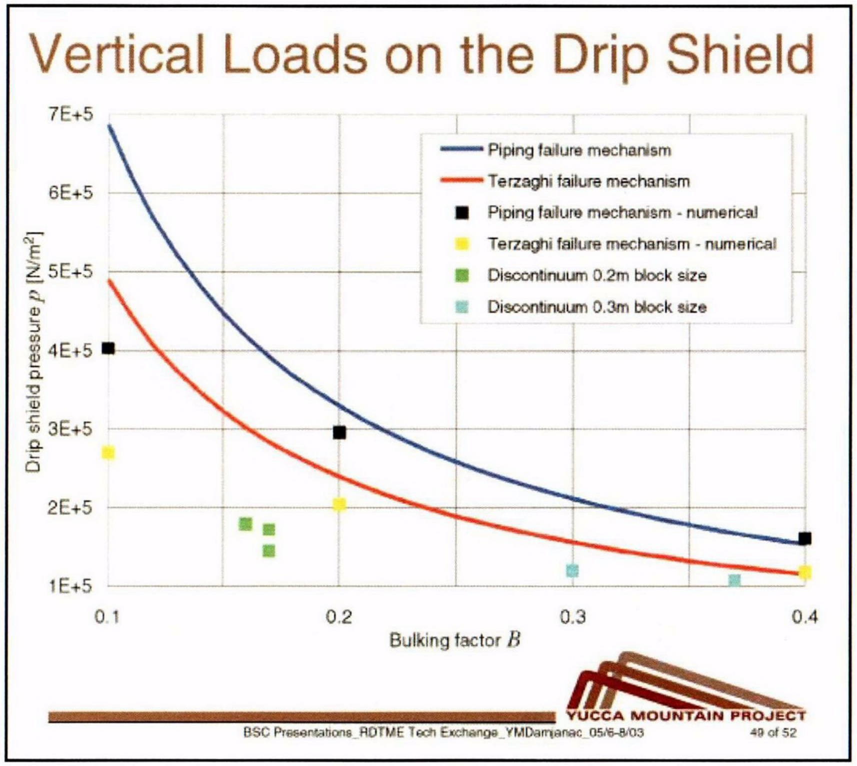
Long-Term Drift Configuration With Accumulated Rockfall
Hmax ≈ 40m for bf = 1.1
Hmax ≈ 10m for bf = 1.5
bf = Bulking Factor

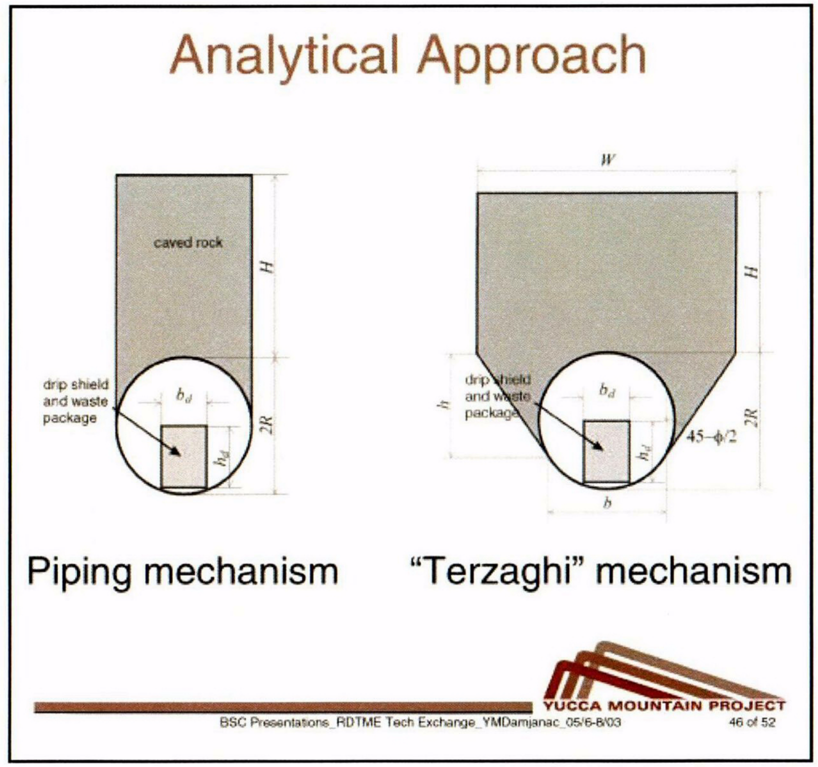
- Potential Maximum Height of Rubble
  - Bulking behavior of broken rock defined in terms of bulking factor
  - Shape of rock-failure zone from engineering experience
- Height of Rubble Determines Magnitude of Mechanical Loading of Drip Shield
- Values of Bulking Factor Typically in the Range of 1.25-1.35

C10

Mechanical Loading
From Accumulated Rockfall Rubble

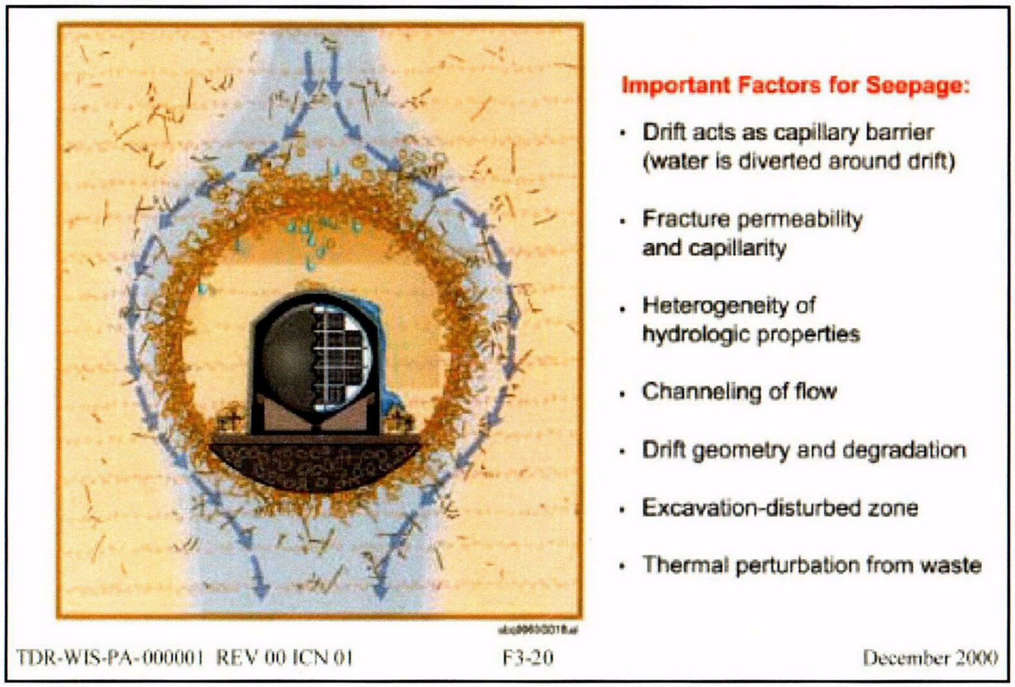
DOE Has Considered Several Approaches to Estimating Drip Shield Loading from Accumulated Rockfall

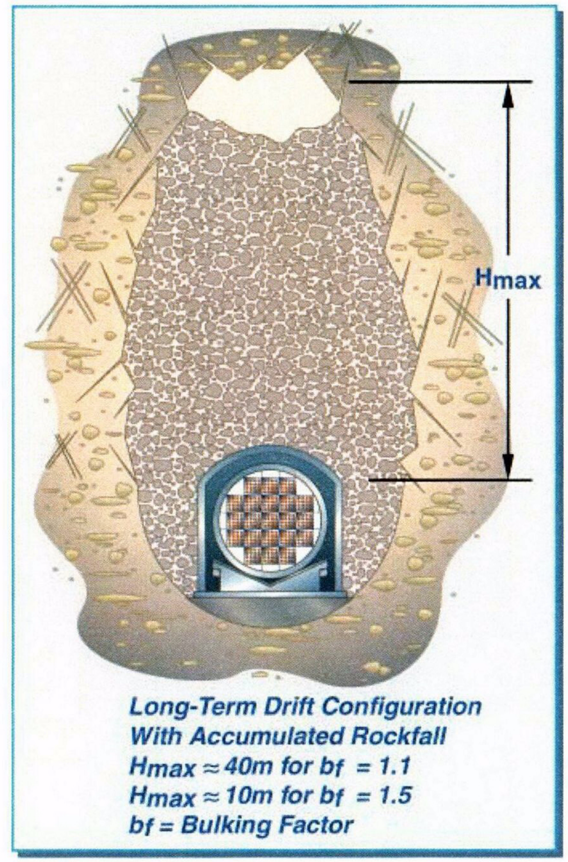




Amounts of Accumulated Rockfall Rubble (Change in Emplacement Drift Configuration)

Models for Basecase Assessment of Heat Flow, Seepage, and Engineered Barrier System Performance Should Use the Long-Term Configuration of Emplacement Drifts

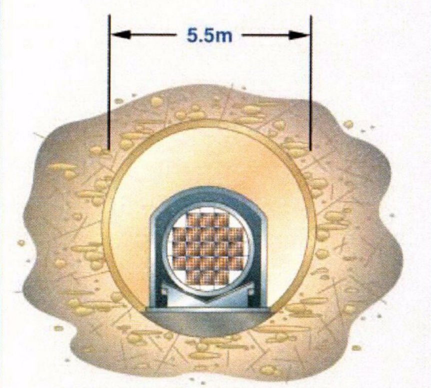




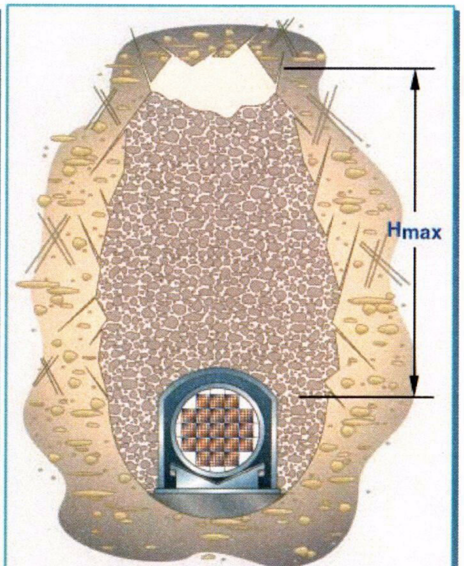
C12

Drift Degradation Rates

Drifts Are Expected to Degrade and Fill with Rubble Within A Few Hundred Years After Cessation of Drift Maintenance



Initial Drift Configuration With Drip Shield and Waste Package

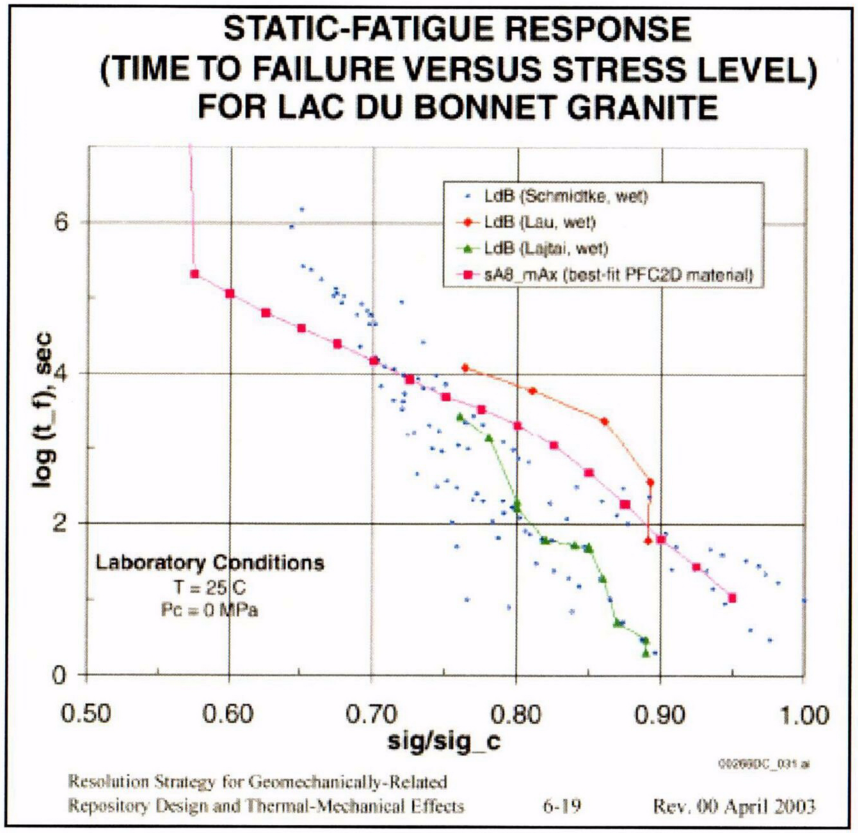


Long-Term Drift Configuration With Accumulated Rockfall
Hmax ≈ 40m for bf = 1.1
Hmax ≈ 10m for bf = 1.5
bf = Bulking Factor

- Preclosure Period
  - Stable openings can be expected
- Postclosure Period
  - Initial tens of years for ground support disintegration
  - Additional tens of years for drift degradation
  - Anticipated standup time of up to a few hundred years for an emplacement drift

C13

Drift Degradation Rates



- DOE proposed using static fatigue response data to estimate drift degradation rates
- Static fatigue testing (order of days) is preferred to conventional compression testing (order of tens of seconds) for estimating short-term (order of months) behavior of underground openings
- Using static fatigue testing to estimate long-term (hundreds to thousands of years) behavior of underground openings is unprecedented

C14

Status of Issue Resolution

- DOE and NRC Staff Views Appear Similar Regarding the Following Items
  - Dynamic rock-block impact on drip shield
  - Occurrence of drift degradation and accumulated rubble within 10,000 yr

- DOE and NRC Staff Views Differ Regarding the Following Items
  - Magnitude of drip shield loading from accumulated rubble
    - DOE has considered several loading estimates but has not indicated which estimates it intends to use
    - DOE estimates from micromechanical modeling are significantly smaller than the estimates from analytical modeling

Status of Issue Resolution (Continued)

- DOE and NRC Staff Views Differ Regarding the Following Items
  - Rates of drift degradation and rubble accumulation
    - DOE proposed use of static fatigue response data to estimate drift degradation rates is unprecedented
    - Empirical information regarding state of underground openings with tens to hundreds of years' history may help alleviate the staff concern regarding the proposed DOE approach
  - Representation of drift degradation and rubble accumulation in performance assessment
    - Drift degradation was "screened out" for DOE performance assessment for site recommendation
    - DOE nominal scenario description in "TSPA-LA Methods and Approach" does not include drift degradation.

PRECLOSURE SAFETY ANALYSIS METHODOLOGY AND DRIFT-DEGRADATION EVALUATION

REPOSITORY DESIGN AND THERMAL-MECHANICAL EFFECTS KEY TECHNICAL ISSUE

Introductory Remarks by

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United States Nuclear Regulatory Commission
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146th ACNW Meeting
October 22, 2003

Outline of Presentation

- Objective and Scope of Briefing
- Risk Significance
- Introduction of Speakers

Objective and Scope of Briefing

- Present Two Risk-Significant Items that are the Focus of RDTME KTI Staff
- Provide an Update on the Pre-closure Safety Analysis Methodology and Associated Computer Program (PCSA Tool)
- Present Recent Staff Analyses of the Long-Term Drift-Degradation and Its Potential Effects on Engineered Barrier Design and Performance

Why These Two Topics?

- PCSA Tool
  - PCSA Provides the Overall Methodology for Evaluating the DOE Repository Design and Assessing the Risk Significance of its Components
  - PCSA is the Primary Means for Staff to Determine Whether the Pre-Closure Performance Objectives are met
  - Staff will also use PCSA to Review the DOE Identification of Structures Systems and Components Important to Safety
- Drift Degradation
  - Long-term Degradation of Emplacement Drifts is Ranked as "High" in Risk Significance because of its Potential Effects on Long-Term Performance of the Engineered Barrier System
  - The Timing and Extent of Drift Degradation and its Possible Effects are the Subject of Several Agreements between NRC and DOE

Introduction of Speakers

- PCSA Tool and Example: Dr. Bis Dasgupta (CNWRA) and Robert K. Johnson (EPAB/PAS)
- Second Presentation:
  - Part-1, Drift Degradation Evaluation: Dr. Goodluck Ofoegbu (CNWRA)
  - Part-2, Effects on the Drip Shield: Dr. Douglas Gute (CNWRA)

Scope of RDTME KTI

- Evaluate Design, Construction, and Operation of the Geologic Repository Operations Area
- Includes both Pre-Closure and Post-Closure Performance Objectives
- Takes into Consideration Coupled Processes, Including Long-Term Thermal-Mechanical and Seismic Effects
- Pre-Closure Aspects are Covered Under Ten Topics (Details Presented During Staff Presentation at the 127th ACNW Meeting)
- Construction, and Operations Subissues Covered Under RDTME KTI are mainly of Interest During Pre-Closure, but Design Concerns Affect Both Pre-Closure and Post-Closure Performance
- RDTME KTI Work Organized Under Four Subissues
  - Design Control Process
  - Seismic Design
  - Thermal-Mechanical Effects
  - Seals

Brief Status of Issue Resolution

- Pre-Closure
  - 9 Agreements Related to Pre-Closure Topics
    - 2 Agreements: Identification of Hazards and Initiating Events
    - 2 Agreements: Identification of Structures, Systems, and Components important to Safety
    - 5 Agreements: Design of Structures, Systems, and Components Important to Safety and Safety Controls

- RDTME KTI
  - Subissues 1 (Design Control Process) and 4 (Repository Post-closure Seals) are closed
  - 23 Agreements Dealing with Subissues 2 (Seismic Design) and 3 (Thermal-Mechanical Effects)
    - 3 Agreements: Mechanical Characterization of Repository Rock Mass
    - 13 Agreements: Stability of Emplacement Drifts Through Permanent Closure
    - 4 Agreements: Characterization of Rockfall and Configuration of Emplacement Drifts After Permanent Closure
    - 1 Agreement: Assessment of Rockfall Effects on EBS Performance (In addition to other agreements under CLST KTI)
    - 2 Agreements: Thermal-Mechanical Effects on Hydrological Characteristics

Total-system Performance Assessment (TPA) Version 5.0 Code

146th Meeting of
Advisory Committee on Nuclear Waste
October 21-23, 2003

Christopher Grossman 301-415-7658 cjg2@nrc.gov
Division of Waste Management
U.S. Nuclear Regulatory Commission

Overview

- Purpose of TPA Code
- TPA 5.0 Development Process
- Role of External Peer Review in TPA 5.0 Development
- TPA 5.0 Modifications
- Path Forward

TPA: A Review Tool

- TPA provides a flexible framework to independently review pre-licensing activities and a license application for the proposed repository at Yucca Mountain.
- TPA uses approaches based on fundamental principles, where possible, to simulate the repository behavior and allow for computational efficiency.
- Where possible, the approaches are based on available data.

October 22, 2003 Slide 3 of 20

TPA 5.0 Development Process

- Staff began planning for TPA 5.0 modifications during 2001.
- Staff identified modifications to enhance the capability of the TPA code as a review tool.
- Modifications are described in the Software Requirements Description[1] and documented in a series of software change requests, which are maintained at the Center for Nuclear Waste Regulatory Analyses (CNWRA).
- Development activities continued through July, 2003.
- Confirmatory testing activities coincided with the end of development to provide additional confidence in the TPA code.

October 22, 2003 Slide 4 of 20

TPA 5.0 Planning

- Modifications were identified considering information from several sources:
  - External Peer Review of TPA 3.2[2] (EPR)
  - Total System Performance Assessment for the Site Recommendation[3]
  - Supplemental Science and Performance Analyses[4]
  - Utilization of TPA Version 4.0 and 4.1
  - Discussions with KTI leads
- Modifications were identified to enhance the capability of the TPA code as a review tool.

Planning Criteria

- The modifications for TPA 5.0 were included to satisfy one or more of the following criteria:
  - Prepare capability to review a potential license application for a Yucca Mountain repository
  - Improve staff understanding of the repository system
  - Enhance flexibility in models and input/output
  - Maintain computational efficiencies
- Many of the modifications considered were also recommendations from the EPR.

Modifications

- Conceptual model modifications incorporate major enhancements into TPA 5.0 for the following areas:
  - Near-field chemistry
  - Drip shield lifetime
  - Waste package lifetime
  - Source term
  - Unsaturated and saturated zone transport
  - Igneous activity
- Some modifications incorporate minor enhancements to existing conceptual models.
- Modifications to the executive driver accommodate added flexibility and new data characterizing the site.

Conceptual Model Modifications

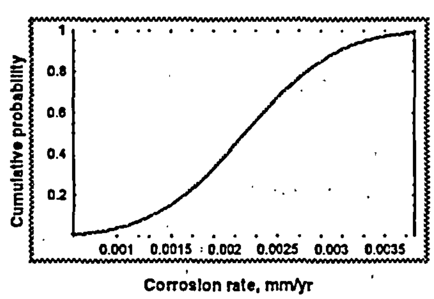
TPA 4.1 → TPA 5.0

Near-Field Chemistry

- New conceptual model describes pH, Cl^-, and F^- evolution to improve realism in corrosion modeling.
- Process-level modeling developed ranges for in-drift concentrations during the dry-out period based on ambient pore-water compositions and estimated compositions of highly concentrated brines.
- In-drift concentrations before and after the dry-out period are based on ambient bore-hole water (i.e., J-13). Capability to specify in-drift concentrations as a function of temperature.
- New chemical evolution model results in an increased chance for localized corrosion to occur.

October 22, 2003 Slide 9 of 20

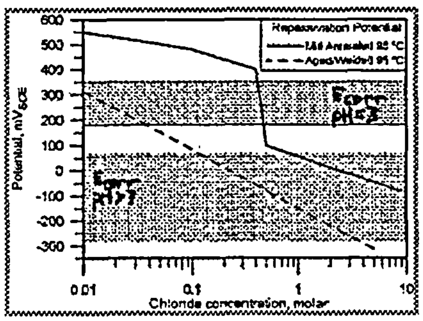
Drip Shield Lifetime



- A new parametric model determines *drip shield thickness using general* corrosion rates at each time step.
- Ti Grade 7 current densities in range of 10^{-8} to $5x10^{-7}$ A/cm^2 (pH range 2.1 to 10.7, [Cl] range 0.1 to 1M, 95 °C)
- Corrosion rates ranging from $8.7x10^{-5}$ to $4.3x10^{-3}$ mm/yr (assumed 0.1 and 99.9 percent *quantile values of a normal* distribution)
- Drip shield failure time affects the water contacting the waste package. The model allows the flexibility to select different chloride concentrations in contact with waste packages.

October 22, 2003 Slide 10 of 20

Waste Package Lifetime: Weld Corrosion



- Thermally aged specimens (5 min. at 870 °C) of Alloy 22 displayed localized corrosion at lower temperatures (as low as 60 °C) and at lower chloride concentrations (as low as 0.01 M).
- Weld corrosion model uses localized corrosion parameters bounded by data for thermally aged Alloy 22.
- The geometry of weld corrosion determines the amount of water entering the waste package and available for radionuclide release, in the case of weld failure.

Source Term: High-Level Waste Glass

- Estimated glass dissolution rates can be dependent on many variables (e.g., glass formulation, testing methods, test conditions)
- MANY experiments completed to determine dissolution rates
- Typical rate expression:

$$\text{Rate} = S\{ k[1-(Q/K)]\} \qquad k = k_o\, 10^{\eta\, pH} \exp(-E_a/RT)$$

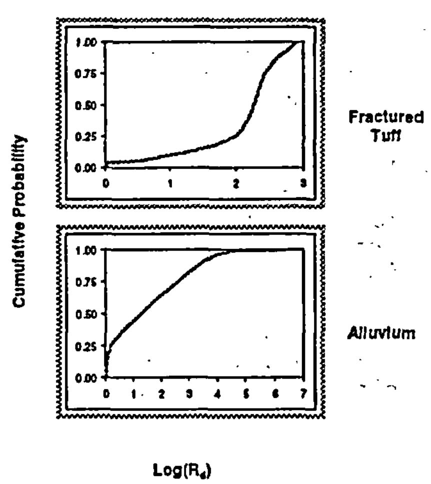
S - surface area of glass immersed in solution
k - forward dissolution rate
Q - concentration of dissolved silica in the solution
K - a quasi-thermodynamic fitting parameter equal to the apparent silica saturation value for the glass

k_o - intrinsic dissolution rate in g/m^2-day
η - pH dependence coefficient
E_a - activation energy in kJ/mol
R - gas constant (8.314 kJ/mol-K)
T - temperature in Kelvin

Source Term: Diffusive Release

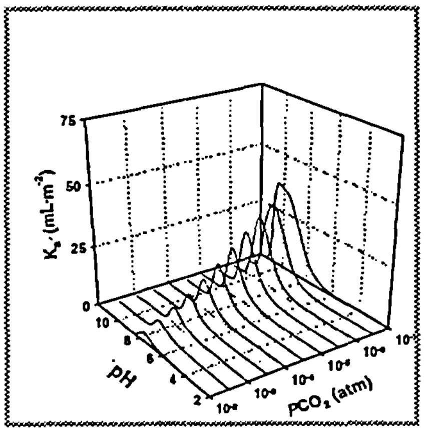
- Model accounts for radionuclide diffusion in films of water connecting the spent fuel with the outside of the waste package.
- User defines diffusive path length and water film cross-section. Model assumes zero radionuclide concentration at terminus of water film, and solubility limit at point of contact of film with spent fuel.
- Diffusion model improves review capability.

Source Term: Colloids



- Fraction of the EBS release specified for a particular radionuclide (Pu, Am, Th, & Cm) to represent the portion irreversibly-sorbed to colloids.
- Radionuclides irreversibly-sorbed to colloids can be permanently removed by filtration in the unsaturated zone matrix. No retardation of colloids in fractures.
- Radionuclides irreversibly-sorbed to colloids are retarded in saturated zone.
- Transport properties of aqueous radionuclides adjusted to reflect reversible attachment to colloids.

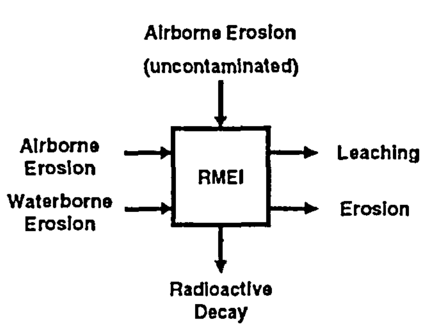
Unsaturated and Saturated Zone Flow and Transport



- New radionuclide transport model links retardation to geochemistry.
- Process-level modeling calibrates response surface to experimental data as a function of pH and PCO_2 for actinides (i.e., Pu, Am, Th, U, and Np).
- PCO_2 and pH sampled over ranges representative of YM waters.
- Improves computational efficiency and flexibility.
- Results in a narrower range of retardation factors.

October 22, 2003 Slide 15 of 20

Igneous Activity



- Ash redistribution model for the mobilization of ash that lands in the catchment basin north of Fortymile Wash.
- Model tracks ash thickness and radionuclide concentration at the source term near eruption and the RMEI location.
- Model provides increased flexibility to examine impacts of remobilization parameters.

October 22, 2003 Slide 16 of 20

Summary and Path Forward

- TPA provides a framework to assist the review of a potential license application for a Yucca Mountain repository and staff's independent understanding of the repository system.
- Modifications in TPA 5.0 provide improved realism and flexibility to assist staff reviews and understanding.
- TPA 5.0 builds on TPA 4.0/4.1 and includes many of the external peer reviewers' recommendations.
- Staff continues to evaluate parameters and complete confirmatory testing activities.
- Staff will continue to utilize TPA to assist its reviews and improve its understanding for the high-level waste program.

October 22, 2003 Slide 17 of 20

Supplementary Information

October 22, 2003 Slide 18 of 20

Other Modifications

- A more realistic representation of the shallow infiltration and associated uncertainty by accounting for run-on/off effects.
- CladdingCorrectionFactor is set by user for constant protection against radionuclide release. Also, alternative DOE model for cladding degradation implemented to enhance review capabilities.
- Updated localized corrosion parameters with recent CNWRA data. Time-dependent correction term for the effect of microbial-induced corrosion on the critical potential for localized corrosion.
- Uncertainties reflected in Calico Hills non-welded thickness and variability in unsaturated zone dispersivity and allows unsaturated zone flow to share matrix and fracture flow.
- Uncertainties in saturated zone streamtube dimensions and changes in flux following climate change.
- Determination of receptor dose consistent with criteria established in 10 CFR 63.
- Categories of disturbance parameters for mass loading and occupancy time.

References

[1] Janetzke, R.W., S. Mohanty, C.J. Grossman, L. Browning, R.B. Codell, R.W. Fedors, B.E. Hill, O. Pensado, D.R. Turner. "Software Requirements Description for the Total-System Performance Assessment Version 5.0 Code – Amendment 1." San Antonio, Texas: CNWRA. September 23, 2002. ML031190317.

[2] Weldy, J.R. and J. Peckenpaugh. "Response to the External Peer Review of the Total-System Performance Assessment Version 3.2 Code." CNWRA 2001-02 Rev 1. San Antonio, Texas: CNWRA. 2003. ML031681060.

[3] CRWMS M&O. "Total System Performance Assessment for the Site Recommendation." TDR-WIS-PA-000001. Rev. 00 ICN 01. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc. 2000.

[4] CRWMS M&O. "Supplemental Science and Performance Analyses." TDR-MGR-MD-000001. Rev. 00. Las Vegas, Nevada: CRWMS M&O. 2001.

RESPONSE TO THE EXTERNAL PEER REVIEW OF THE TOTAL-SYSTEM PERFORMANCE ASSESSMENT VERSION 3.2 CODE

146th Meeting of
Advisory Committee on Nuclear Waste
October 21-23, 2003

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Division of Waste Management
U.S. Nuclear Regulatory Commission

Main Contributors: Lane Howard (CNWRA)
James Firth (NRC)

Overview

- Purpose and goals of external peer review
- External peer review comments
- Staff response to the comments
- TPA code changes
- Summary

Rationale for Performing External Peer Review of TPA 3.2

- ACNW recommended an external peer review of the TPA code in October 1997
- The review was conducted during the summer of 1999 to document the capabilities and limitations of the TPA 3.2 Code and to evaluate its suitability for use in reviewing the DOE License Application
- The external peer review should help the NRC staff plan enhancements to the TPA code in preparation for the potential licensing review
- The external peer review complemented other steps used to provide confidence in the TPA code

Composition of External Peer Review Group

- External peer review group (ERG) consisted of eight members with expertise in:
  - Rock mechanics and mining engineering
  - Volcanology
  - Hydrology
  - Material science and corrosion engineering
  - Geochemistry
  - Performance assessment
  - Features, events, and processes analysis
  - Health physics

Purpose and Goals of External Peer Review Group

- ERG was asked to perform the following items pertaining to the TPA code
  - Examine the methods and assumptions
  - Recommend improvements for future versions of the code
  - Evaluate implementation of conceptual models, including parameter selections
  - Determine whether the NRC approach to TPA is sufficient to review the DOE License Application for the proposed Yucca Mountain repository
- Each member of the ERG submitted an independent review (not a consensus report)

External Peer Review Comments

- The code was well-developed and captured the important physical processes associated with the repository
- The code would be sufficient in technical quality and flexibility to be used in the review of the DOE License Application; however, improvements would enhance the code
- Reviewers provided several suggestions for improvements in the code, including comments on:
  - Modeling coupled processes
  - Improving the modeling of chemical composition of water
  - Data used in modeling the saturated zone
  - Basis for selecting the radionuclides tracked
  - *Code documentation*

Response to External Peer Review Comments
Processing and Tracking

- A spreadsheet is being used to track the resolution of the 233 unique comments
  - Grouped according to issue areas
  - Assigned to appropriate NRC and CNWRA staff
  - Developed responses
  - Documented in the final report
- All comments were addressed
- The spreadsheet is updated periodically

October 22, 2003 7

Response to External Peer Review Comments
Staff Response to Comments

- Most responses to comments did not require enhancements to the TPA code
- Responses to comments that resulted in enhancements to TPA code
  - Response was addressed as TPA code changes in version 4.0 or 4.1 or
  - Response would be considered in a future version of the TPA code (TPA 5.0)
- Responses to comments that were addressed through improvements in TPA code documentation
  - Justification was provided in User's Guide 4.0 or
  - Justification will be provided in User's Guide 5.0

October 22, 2003 8

Response to External Peer Review Comments
Staff Response to Comments

- All comments were addressed in the Response to the External Peer Review report
  - Citation of a documented sensitivity analysis that indicated the issue does not affect the calculation
  - Response indicated that assumptions made in the modeling or selection of parameters are reasonable

October 22, 2003 9

TPA Code Enhancements – Both External Peer Review and Staff Generated

- Changes made in Versions 4.0 and 4.1 of the TPA code
- Changes in Version 5.0 of TPA code will be covered in following presentation

October 22, 2003 10

Changes in TPA 4.0 or 4.1 Code

- Based upon ERG comments
  - Ability to specify different waste package failure modes (bathtub or flow-through models) for different failure types (seismic, corrosion, initial defects, etc.)
- Based upon staff recommendations
  - Modified the amount of water that can enter the waste package by adding time-dependent flow-rate factors

October 22, 2003 11

Summary

- The external peer review identified some areas of the TPA code that could be improved
- Several of the comments were addressed within Versions 4.0, 4.1, and 5.0 of the TPA code
- The external peer review of the TPA 3.2 Code provided additional confidence that the code reasonably models the repository system and is appropriate for use in the review of the DOE License Application

October 22, 2003 12

References

Weldy, J.R., G.W. Wittmeyer, and D.R. Turner. "External Peer Review Of The Total-System Performance Assessment Version 3.2 Code." CNWRA 2000-01. San Antonio, Texas: CNWRA. 1999.

Weldy, J.R. and J. Peckenpaugh. "Response To The External Peer Review Of The Total-System Performance Assessment Version 3.2 Code." CNWRA 2001-02 Rev 1. San Antonio, Texas: CNWRA. 2003.

Supplementary Information

Members of the External Review Group for the TPA Version 3.2 Code

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  Rock Mechanics and Mining Engineering
- Dr. Paul Delaney - U.S. Geological Survey
  Volcanology
- Dr. Ghislain de Marsily - Laboratoire Géologie Appliquée Université Pierre and Marie Curie
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- Dr. Robert Kelly - University of Virginia
  Material Science and Corrosion Engineering
- Dr. Gérald Ouzounian - Agence Nationale Pour La Gestion Des Déchets Radioactifs (ANDRA)
  Geochemistry
- Dr. Brian Thompson - Independent Consultants
  Overall Performance Assessment
- Dr. Frits van Dorp - Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (NAGRA)
  Features, Events, and Processes Analysis
- Dr. F. Ward Whicker - Colorado State University
  Health Physics